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ScienceDirect

Energy Procedia 78 (2015) 400 – 405

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Computing thermal bridge of VIP in building retrofits using DesignBuilder

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Abstract

A high-performance insulation solution, such as vacuum insulation panel (VIP) reduces heat losses in a retrofitted building envelope. However, discontinuity of insulation material causes thermal bridges. A significant thermal bridge effect at the edge of VIP must be taken into account in the overall heat transfer coefficient (U-value) calculation; but is often omitted due to difficulties especially with numerical calculations. This study describes a modeling approach used to accurately evaluate the effect of thermal bridges on the overall U-value of building envelope. The thermal bridge and U-value were modeled and computed respectively using DesignBuilder which is based on EnergyPlus dynamic simulation engine. Correlation was drawn between experimentally determined U-value of VIP retrofitted building walls and the principal computation parameter.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Vacuum insulation panel, VIP; thermal bridge; heat transfer coefficient, U-value; DesignBuilder.

1. Introduction

At present, several buildings have been insulated with vacuum insulation panels (VIP) [1-4]. Typically, the U_o of VIP retrofitted building envelope (walls and floors) is undesirably increased by thermal bridges. Three categories of thermal bridges can be identified; at the VIP material level, component VIP level and building component level due to differences in thermal conductivity between the core and envelope materials, air gaps between adjacent VIPs and mounting spacers, and assembly of component VIP to other building envelope components, respectively [5].

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Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.683

Generally, the magnitude of thermal bridge depends on thickness and thermal conductivity of the envelope, and properties of core material and edge. For instance, simulated results showed that the change of *U*-value in percent $((U_o\text{-}U_u)/U_u = \Delta U/U_u)$ increased by 175 % and 29 % for component VIPs (size of 500 mm × 500 mm × 20 mm, thermal conductivity of 4 mW/(m·K), with gap of 5 mm between adjacent VIPs) with laminated aluminium (Al) foil and metalized multi-layered film, respectively [6]. Linear thermal bridges characterize the thermal bridge at the edge of a VIP. In some cases, point thermal bridges occur if mounting systems such as spacers are inserted at junctions between VIPs to secure their adhesion onto a wall. U_o, including ψ_{length} and ψ_{point} can be evaluated by [6]:

$$U_o = \frac{(U_u \cdot A + \sum_i \Psi_{i,length} \cdot l_i + \sum_j \Psi_{j,point} \cdot n_j}{A} \tag{1}$$

$$U_u = \left\{ \frac{1}{\alpha} + \sum \frac{d_i}{\lambda} + \frac{1}{\alpha_{out}} \right\}^{-1} = \left\{ \frac{1}{\alpha} + \sum \frac{1}{\Lambda} + \frac{1}{\alpha_{out}} \right\}^{-1} \tag{2}$$

U_u can be calculated by Equation 2. However it is difficult to evaluate ψ_{length} (predominant as compared to ψ_{point}) in buildings with multiple component layers. An analytical approximation model for calculating ψ_{length} of building component was reported in [7]. Analytical computations are accurate but somewhat strenuous. Alternatively, computer modeling and computational method is rapid and quite simple; provided that simulated or computed results are verified and validated. In this study, the components of building envelope were modeled using DesignBuilder; a building energy simulation software based on EnergyPlus dynamic simulation engine. Thereafter, the *U*-value of building walls was computed using computation algorithms programmed in the software based on BS EN ISO 6946. Although the software is versatile, accurate and user friendly, the critical *U*-value computation parameter, termed percent bridging in DesignBuilder is usually neglected. For instance, it is possible to accurately model a building envelope and its U_o if the required U_o is already known. On the other hand, if the required U_o is unknown, it is essential to impute a numeral coefficient for the percent bridging parameter. This parameter estimates the effect of thermal bridging on the computed *U*-value. Without specifying the percent bridging, the software calculates U_u which is not the true *U*-value. The objective of this study is to investigate the numerical coefficient of the principal U_o computation parameter, which is percent bridging.

To meet the objective of this study, a number of building cases were chosen from literature based on accessibility of key data criteria to support modeling in DesignBuilder. Thus the percent bridging coefficient was correlated from experimental or theoretical U_o results in literature. In addition, simulations were carried out to determine the effect of U_u and U_o on building energy consumption for peak winter season.

Nomenclature

A	area, m^2
d	thickness, m
l	length, m
n	number of all thermal bridges
U_o	overall heat transfer coefficient, W/(m^{2}K)
U_u	bulk heat transfer coefficient without thermal bridge, W/(m^{2}K)
U_o'	overall heat transfer coefficient computed with percent bridging coefficient of 3.21
α_{in}	heat transfer coefficient at the inner wall surface, W/(m^{2}K)
α_{out}	heat transfer coefficient at the outer wall surface, W/(m^{2}K)
λ	thermal conductivity, W/(mK)
Λ	heat transfer coefficient of building component layer, W/(m^{2}K)

2. Methods

2.1. Building envelope description

Various subtasks were performed. First, an experimental database was developed as core parameters for modeling in DesignBuilder. Data sets recorded included experimentally or theoretically determined U_o, components of the building envelope, thickness of each component layer, and thermal conductivity of VIP. In all, ten building cases were considered in this study (i.e. eight wall cases and two floor cases). Further, building cases were modeled in DesignBuilder as depicted in Fig. 1. Fig. 1 (left) shows a modeled brick-stone wall representing one of the ten building cases studied. Fig. 1 (right) shows the framework for computing U_u and U_o. Table 1 displays boundary conditions to compute the U-values. Finally, the percent bridging coefficient was computed using data analysis tool.

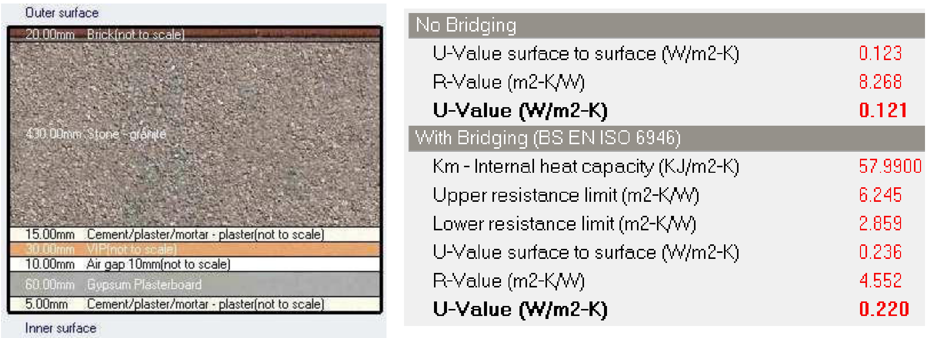

Fig. 1. Façade layers modeled in DesignBuilder (left) and computation of U_u and U_o (right).

Table 1. Boundary conditions for numerical computations.

Building envelope	Boundary	Inner surface	Outer surface
Wall	Surface resistance	0.13 (m^2K/W)	0.04 (m^2K/W)
Floor	Surface resistance	0.17 (m^2K/W)	0.04 (m^2K/W)

2.2. Building model description

In order to evaluate the effect of both U_u and U_o on building energy consumption, simulations were carried out on a model building, using the U-values of the building cases in this study as the U-value of the building envelope. The model building (see Fig. 2) is a 2-storey educational facility with total floor area of 466.02 m^2 and gross wall area of 730.61 m^2. It was assumed that the model building was situated in Seoul, South Korea. Thus hourly weather data of

Fig. 2. Model of educational facility.

Seoul, in TMY form was used. The zone temperature was controlled to 20 ºC for heating in peak winter duration from 1st December-31st January.

3. Result and discussions

U_o values adopted from [1, 8], U_u and numerical coefficient of percent bridging computed in DesignBuilder for ten building cases are listed in Table 2. Thermal bridges are critical from the viewpoint of building physics. Adding the effect of thermal bridges reduces the effective size of VIP and increases the thermal conductivity of VIP. From Equation 2, an increase in thermal conductivity would undesirably result in an increase of the overall *U*-value. Considering the wall cases listed in Table 2, the percent bridging coefficient lies in the range of about 2.0~4.0. Considering brick/stone walls from Table 2, the magnitude of U_o was double or almost double that of U_u for cases I, III, IV, V, and VI. Consequently, the percent bridging coefficients for cases I, III, IV, V, and VI were the highest. Cases I, III, IV, V, and VI corresponded to walls with insulation thickness in the range 20~40 mm. Adopting a pessimistic (assurance) approach, cases I, III, IV, V, and VI were plotted as illustrated in Fig. 3.

Table 2. *U*-values and corresponding coefficient of percent bridging.

Case	Building envelope	*d* (mm)	U_o (W/m^{2}K)	U_u (W/m^{2}K)	Percent bridging
I	Brick wall	40	0.16	0.08	3.20
II	Brick wall	40	0.13	0.09	2.20
III	Brick wall	35	0.19	0.10	3.40
IV	Brick/stone wall	30	0.22	0.12	3.85
V	Stone wall	20	0.35	0.19	3.10
VI	Brick wall	20	0.23	0.16	3.10
VII	Timber wall	40	0.14	0.09	2.30
VIII	Floor	20	0.17	0.16	0.50
IX	Floor	20	0.15	0.13	1.00
X	Curtail wall	18	0.22	0.21	0.40

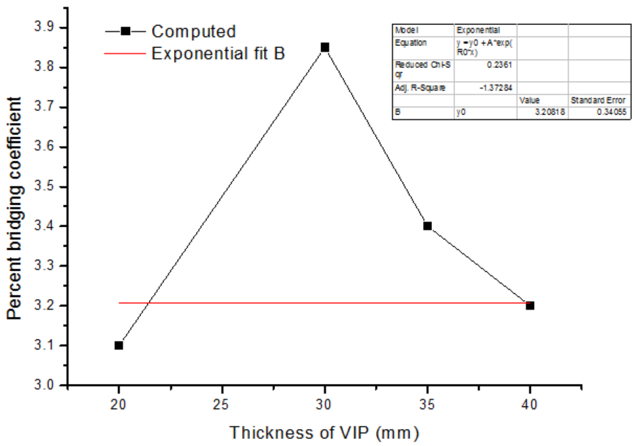

Fig. 3. Relationship between percent bridging and VIP thickness.

It is worth noting that cases I and II had the same insulation thickness but different percent bridging coefficient. This is mainly attributed to disparity of their building envelope thicknesses. Likewise, cases V and VI had the same insulation thickness as well as percent bridging coefficient even though their respective U-values differed. However, this is chiefly due to the material properties of the building envelope components of cases V and VI (not reported in detail in this paper). Also, cases VII, IX and X showed the least percent bridging coefficient in the range 0.4 ~ 1. For case X, the big size (1 m^2) of the VIP element minimized thermal bridges. Also the total thickness of the curtain wall was only 32 mm (Glass / VIP / Glass). From Fig. 3, an exponential fitting resulted in a value of approximately 3.21, at a standard deviation of about 0.34. The result of 3.21 was based on cases I, III, IV, V, and VI, nonetheless U-value computations using 3.21 as the percent bridging coefficient (U_o') for all building wall cases (except curtain wall) was done to check the validity of the fitted value; results are reported in Table 3.

Table 3. Reference U_o and U_u compared with U_o'.

Case	Building envelope	d (mm)	U_o (W/m^{2}K)	U_u (W/m^{2}K)	U_o'(W/m^{2}K)
I	Brick wall	40	0.16	0.08	0.160
II	Brick wall	40	0.13	0.09	0.140
III	Brick wall	35	0.19	0.10	0.185
IV	Brick/stone wall	30	0.22	0.12	0.207
V	Stone wall	20	0.35	0.19	0.354
VI	Brick wall	20	0.23	0.16	0.232
VII	Timber wall	40	0.14	0.09	0.153

From Table 3, by comparing the disparity between U_o and U_o' to the disparity between U_o and U_u, it can be inferred that the disparity between U_o and U_o' was far less as compared to the latter. To determine a common coefficient is no mean task. In reality, the percent bridging coefficient is complex and depends not only on the magnitude of the thermal bridges of the VIP, but also on the material properties, component thicknesses, overall building envelope thickness, prevailing boundary conditions, among others. Nevertheless, with reference to the building cases considered and most especially the brick and stone wall building envelopes, a percent bridging coefficient of 3.21 was somewhat accurate to compute U_o in DesignBuilder.

Energy used for heating in peak winter season (1st December-31st January) based on the model described in Section 2.2 and change in energy used, in percent ((E_o-E_u)/E_u), are tabulated in Table 4. As expected, lower U_u resulted in lower heating energy demand than U_o. Invariably, modeling and simulations based on U_u would be erroneous; specifically if the U-value is not already known. The percent bridging coefficient is important to mitigate such errors.

Table 4. Heating energy for U_o and U_u.

Case	Building envelope	Heating load based on U_o, E_o (GJ)	Heating load based on U_u, E_u (GJ)	ΔE (%)
I	Brick wall	47.23	44.45	6.25
II	Brick wall	46.19	44.80	3.11
III	Brick wall	48.25	45.15	6.85
IV	Brick-stone wall	49.27	45.84	7.49
V	Stone wall	53.55	48.25	10.98
VI	Brick wall	49.61	47.23	5.03
VII	Timber wall	46.54	44.80	3.88
VIII	Floor	54.56	54.57	-
IX	Floor	54.57	54.58	-

4. Limitations

In the previous sections, numerical computations have been used to derive the percent bridging coefficient to accurately model and compute the overall *U*-value in DesignBuilder. For those numerical computations, realistic building envelope parameters were adopted into models. Within the context of the building cases considered, the percent bridging coefficient of 3.21 is adequately accurate for brick and stone walls with thickness less than 525 mm and insulated with VIP with thickness in the range 20 mm ~ 40 mm. The derived percent bridging coefficient greatly reduced the disparity between U_o and U_u. However, support systems such as spacers were not modeled. Gaps between VIPs were assumed to be 5 mm in the models, but in reality it may be more or less than 5 mm.

5. Conclusion

The objective of this study was to investigate the percent bridging coefficient for computing the overall *U*-value of buildings insulated with VIPs in DesignBuilder. Sampled building cases were modeled based on real parameters. Building energy simulations showed that the *U*-value had a pronounced effect on heating energy demand. In particular, change in heating energy demand based on bulk *U*-value (without thermal bridge) and overall *U*-value (with thermal bridge) for Brick/Stone walls ranged from about 1.4 GJ to 5.3 GJ; demonstrating a considerable impact, and significance to compute the magnitude of the *U*-value more precisely. Within the building envelope, Brick/Stone walls indicated higher dependence on the magnitude of the percent bridging coefficient as compared to floors. Howbeit, for Timber and Curtain walls, the percent bridging coefficient was lesser. Results showed that the percent bridging coefficient was 3.21, considering the limitations stated. Essentially, the percent bridging coefficient was validated by computing and comparing the *U*-value based on the stated coefficient with the experimentally determined overall *U*-value; and good correlation was deduced. The findings of this study will be knowledgeable to building physicists, academicians and computational building physics software developers.

Acknowledgements

This research was supported by the Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education and Human Resources Program in Energy Technology of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resources from the Ministry of Trade, Industry & Energy, Republic of Korea.

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