Bulgarian Chemical Communications, Volume 48, Special Issue D (pp. 320 – 326) 2016

Numerical simulation and experimental study on thermal properties of trailer house composite envelope with vacuum insulation panels

Haijun Lou, Ankang Kan*, Zhipeng Guo

Merchant Marine College, Shanghai Maritime University, Shanghai, 201306, P.R.China

Received June 5, 2016, Revised September 16, 2016

Due to distinguished thermal performance of vacuum insulation panels (VIPs), i.e. the thermal conductivity is approximately 5-10 times lower than that of traditional thermal insulation material, it has been widely applied for energy conservation purpose, especially as building envelope. To research the thermal characteristic of VIPs composite envelope for trailer house, the VIPs are employed, based on the climate characteristics of the cold zone, and three typical models, namely, the interior adiabatic, sandwich and exterior adiabatic models are constructed. The physical and mathematic models are developed and the numerical comparative analysis of the thermal performance is made under the lager temperature difference condition. Compared among those constructions with the same continuous temperature waves, the damping factor, the delay time, the temperature vibration of interior wall surface, heat transfer flux and the thermal bridge are theoretically analyzed. The results of the simulation imply that, interior adiabatic model of the VIPs composite envelope is the best for the energy conservation, especially in thermal bridge region, reduction the range of the interior temperature fluctuation, radiation thermal cool sensation and improvement thermal comfort index. The work provides the theoretical foundation for the VIPs development and application in building contracture.

Key words: Vacuum insulation panels, Trailer house, Composite envelope construction, Thermal performance, Energy conservation.

INTRODUCTION

The development of cold regions is important for regional economic, military significance and research value. The trailer house can be the temporary working and living place for researchers or staff. As the special outdoor climate in winter, that is, the temperature difference between interior and exterior can be up to 60 °C, thermal performance of the building envelope is vital for energy conservation and personal thermal comfort.

Excellent adiabatic performance of envelope construction, not only can reduce energy consumption, improve indoor thermal comfort, but also can avoid moisture condensation problems of inner wall surface [1]. Due to the distinguished low thermal conductivity, i.e. approximately 5-10 times lower than traditional thermal insulation materials [2-3-4], Vacuum insulation panels (VIPs), has significant advantages as the adiabatic component for trailer house envelope. The VIPs are already introduced to the market in large-scale production, such as reefer containers, civil building envelopes, refrigeration storage room, ice boxes and so on[5]. Some theoretical calculations have been proposed and amount of study has been carried out on the possibilities of VIPs insulated systems. But the reports for the VIPs installation and thermal operation in system are rare.

To whom all correspondence should be sent:
E-mail: ankang0537@126.com

The objective of this paper was to analyse theoretically the thermal insulation models, the internal interface temperature, delay time, thermal inertia index, etc., model the trailer houses wall structure with VIPs and compare the models combined with the exterior temperature variation in cold regions [5].

THERMAL PERFORMANCE OF TRAILER HOUSE ENVELOPE

The envelopes of trailer house, including one door panel, three side panels, one roof panel, and one floor panel, mainly used to reduce the heat leakage and maintain the room temperature. According to the thermal comfort index, interior wall surface temperature closed to the indoor environment temperature means the comfortable feeling [6]. However, the interior surface wall temperature mainly depends on the indoor air temperature and the thermal resistance of the wall. According to some relevant provisions, heat transfer coefficient of trailer house envelope in cold region must be: $k \leq 0.14$ W/(m^2.K), and temperature difference between interior surface and design ambient temperature must be: $\Delta t \leq 4.0$K [7-9]. Too thick wall means high initial investment and transportation costs, while too thin wall means energy consumption and even moisture condensation. Optimal construction of the trailer house envelope can not only provide comfortable living environment, but can also reduce energy consumption. In addition, trailer house belongs to reusable building, which is beneficial to environmental protection, economic.

Minimum thickness of trailer house envelope construction

The minimum heat transfer resistance of building envelope in cold region should meet the requirements of the GB50176-1993, Can be calculated by Eq.(1):

$$R_{0\bullet\min} = \frac{(t_{\mathrm{in}} - t_{\mathrm{ex}})}{[\Delta t]} nR_{\mathrm{in}} \qquad (1)$$

where: $R_{0,\min}$ is minimum heat transfer resistance of the envelope, m^2 K/W; t_{in} is indoor design temperature of the trailer house in winter, K; t_{ex} is outdoor design temperature of the trailer house in winter, K ; n is temperature difference correction factor, n = 1.0; R_{in} is internal surface heat transfer resistance; $R_{\mathrm{in}} = 0.11$ m^2 K/W; Δt means allow error between indoor air and interior wall surface, Δt = 2.5 K.

So, $R_{0,\min}$ = 2.99 m^2 K/W. According to the design Code [8], its heat transfer resistance should be:

$$R = \frac{1}{k} = \frac{1}{0.14} \geq 7.143\mathrm{m}^2 \cdot \mathrm{K/W} \qquad (2)$$

VIPs and polyurethane (PU) as trailer house envelope construction of filling materials, and the thickness of PU layer can be calculated by Eq. (3):

$$R = \sum_1^4 R_i = R_{\mathrm{in}} + \frac{\delta_{\mathrm{f}}}{\lambda_{\mathrm{f}}} + \frac{\delta_{\mathrm{vip}}}{\lambda_{\mathrm{vip}}} + R_{\mathrm{ex}} \qquad (3)$$

Where: R_{ex} is the design exterior surface heat transfer resistance, R_{ex} = 0.04 m^2 K/W; λ_{f} is thermal conductivity of PU, λ_{f} = 0.032 W/(m K); λ_{vip} is thermal conductivity of VIPs, λ_{vip} = 0.007 W/(m K); δ_{vip} is thickness of VIPs, δ_{vip} = 0.02 m.

The exterior protective layers of the trailer house envelope are made of steel plate and galvanized sheet and the interior protective layer is made of stainless steel plate. All the protective layers are very thin and the excellent thermal conductors. R_{ex} and R_{in} are ignored in the calculation. Combined with the Eqs. (2) and (3), the PU layer thickness is 133 mm. In fact, PU layer thickness is 150 mm in this research.

The thermal characteristic parameters of trailer house envelope construction

VIPs cannot be used alone as the envelope of the trailer house, but in form of composite panels with other thermal insulating materials. The following parameters should be confined before the study.

(1) The damping factor. The damping factor refers to the interior air temperature stability of the trailer house envelope, the exterior envelope effect by outdoor integrated temperature or outdoor air temperature harmonic. The damping factor is the ratio of outdoor integrated temperature or outdoor air temperature harmonic amplitude to interior surface temperature harmonic amplitude. For the multilayer envelope, the damping factor can be calculated by the Eq. (4) [8]:

$$v_0 = 0.9e^{\frac{\sum_1^n D_i}{\sqrt{2}}} \frac{S_1 + \alpha_{in}}{S_1 + Y_1} \cdot \frac{S_2 + Y_1}{S_2 + Y_2} \cdots \frac{S_n + Y_{n-1}}{S_n + Y_n} \cdot \frac{Y_n + \alpha_{\mathrm{ex}}}{\alpha_{\mathrm{ex}}} \qquad (4)$$

where: v_0 is the damping factor of the multilayer envelope; D_{i} is thermal inertia index of the layer i; h_{in} is interior surface thermal convective coefficient of the trailer house, W/(m^2·K); h_{ex} is exterior surface thermal convective coefficient, W/(m^2·K); S_1, S_2,…,S_{n} are heat storage coefficients of each layer materials from inside to outside, W/(m^2·K); Y_1, Y_2,…,Y_{n} is surface heat storage coefficient of each layer materials from inside to outside, W/(m^2·K).

(2)The delay time. The delay time is the time difference between the moment that highest (or lowest) interior surface temperature harmonic appears and the moment that the highest (or lowest) outdoor integrated temperature or the highest (or lowest) outdoor air temperature harmonic appears. It can be calculated by Eq. (5) (GB50176-1993):

$$\xi_0 = \frac{1}{15}(40.5\sum_i^n D_i - \arctan\frac{\alpha_{\mathrm{in}}}{\alpha_{\mathrm{in}} + Y_{\mathrm{in}}\sqrt{2}} + \arctan\frac{Y_{\mathrm{ex}}}{Y_{\mathrm{ex}} + \alpha_{\mathrm{ex}}\sqrt{2}}) \qquad (5)$$

where: ξ_0 is the delay time, h; Y_{in} is the heat storage coefficient of interior surface envelope, W/(m^2·K); Y_{ex} is heat storage coefficient of outer surface envelope, W/(m^2·K).

(3) Thermal inertia index. Thermal inertia index D is a dimensionless index to characterize its resistance ability of temperature fluctuations and thermal flux fluctuations. The greater the D value is, the better thermal stability of envelope is. The D of a single material layer envelope can be calculated by Eq. (6)[8] :

$$D = RS = \delta\sqrt{\frac{2\pi C_{\mathrm{p}}\rho}{\lambda T}} \qquad (6)$$

Where: R is thermal resistance, $m^2 \cdot K$ /W; S is thermal storage coefficient, $W/(m^2 \cdot K)$; δ is thickness, m; C_p is specific heat at constant pressure, J/(kg.K); ρ is density, kg/m^3; λ is heat conductivity coefficient, $W/(m \cdot K)$; T is period of fluctuations, s.

For multilayer composite layers envelope, the D value can be calculated by Eq. (7) [8]:

$$\sum_i^n D_i = \sum_i^n R_i S_i \tag{7}$$

(4)The thermal storage coefficient. The thermal storage coefficient is the ratio of the heat flux amplitude through the layer surface to the surface temperature amplitude. It can characterize the merits of the material thermal stability. The greater the thermal storage coefficient is, the better thermal stability is. It's can be calculated by the Eq. (8)[8].

$$S = \frac{A_q}{A_t} = \sqrt{\frac{2\pi\lambda C_p \rho}{T}} \tag{8}$$

where: A_q is heat flux wave-amplitude of layer surface; A_t is temperature wave-amplitude of layer surface.

The types of composite envelope

As the thermal conductivity of VIPs is much less than that of traditional thermal insulated materials, the composite envelope of trailer house, according to VIPs layer location position, can be divided into three types, that is , interior adiabatic (Figure 1a), sandwich (Figure 1b) and exterior adiabatic (Figure 1c).

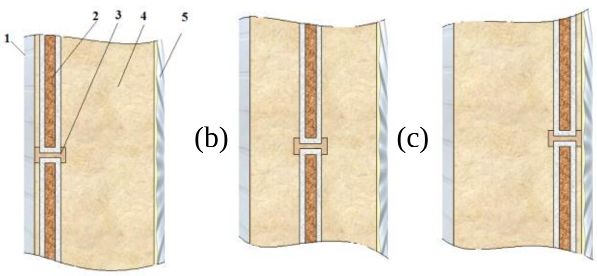


Fig. 1. The adiabatic types of the composite envelope: (a) interior adiabatic, (b) sandwich and(c) exterior adiabatic. (1)- internal stainless steel plate; (2) - VIPs layer; (3) - H-shaped fixed piece; (4) - PU layer; (5) - external steel plate.

VIPs COMPOSITE ENVELOPE CONSTRUCTION MODEL

Heat transfer through trailer house envelope under large temperature difference in cold region is a complicated unsteady process, which is not only affected by the outdoor air temperature, solar radiation, wind speed and so on, but also relates to thermal conductivity, thermal storage coefficient, specific heat at constant pressure, density and thermal performance of envelope material. As the direct calculation for the heat transfer process in trailer house envelope is very complicated, the following necessary assumptions should be made in advance. (1)No clearance exist between each layer; (2) Physical parameters of each layer material does not change with temperature;(3)Ignore the influence of "H-shape connecting piece" and heat transfers in one dimension way;(4) No internal heat source and mass transfer.

Physical model

Internal stainless steel plate and external steel plate are ignored to simplify the models and the physical models are illuminated in Figure 2. The types of composite envelope mainly depend on the location of the VIPs layer. In this physical model, the thickness δ_{vip} of VIPs layer is a constant value, and total thickness $\delta_1 + \delta_2$ for polyurethane layer is also a constant value. When $\delta_1 = 0$, the type is interior adiabatic. While $\delta_2 = 0$, the type is exterior adiabatic. While $\delta_1 = \delta_2 \neq 0$, the type is sandwich.

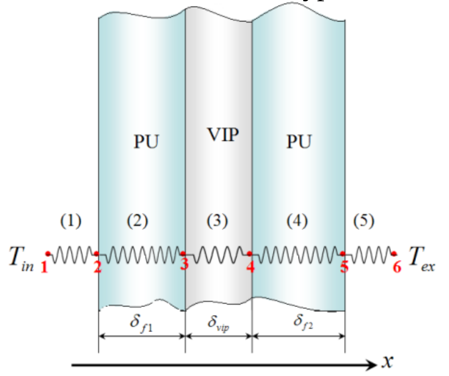


Fig. 2. The sketch of trailer house VIPs composite envelope.

Outdoor temperature

The outdoor temperature is a key variable to calculate the heat flux that transfers from interior to exterior. However, the outdoor temperature changes with time. In a period of time (for example within a month), the diurnal variation of the temperature can be thought as a cyclical fluctuation in 24 hours. Sine (or cosine) function series are always taken to simplify temperature fluctuation for calculation in practice. The real outdoor temperature fluctuation in a certain Chinese cold region in one day of the coldest month in 2013 is collected by the national meteorological station, and the fitting curve is shown in Figure 3.

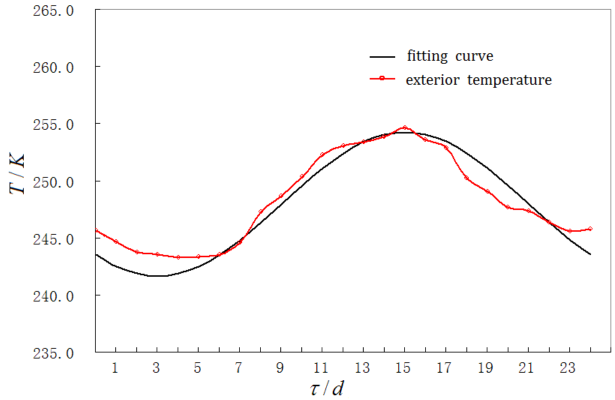


Fig. 3. Actual temperature and fitting curve in the cold region.

Outdoor comprehensive temperature fitting function is:

$$T_{ex,\tau} = 247 + 6.3\cos\left(\frac{2\pi}{24}(\tau - 15)\right) \quad (9)$$

where: $T_{ex,\tau}$ is the corresponding outdoor temperatures at the moment τ, K.

Mathematical model

As the dimension of height and width is much larger than that of thickness of trailer house envelope, no heat source exists and materials of every layer is uniform individually, the thermal conduction of the envelope can be considered as one dimensional way. Based on Fourier's law, a corresponding unsteady differential equation (10) can be established.

$$\frac{\partial T}{\partial \tau} = \frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial x^2} \quad (10)$$

Where, τ is time; x is finite-thickness.

According to the cold region climate characteristics, h_{in} = 8.7 W/(m^2 K), h_{ex} = 19.0 W/(m^2 K). The design indoor temperature in winter is 23^{o}C, relative humidity 30%. That boundary condition is:

$$\begin{cases} \lambda\left.\frac{\partial T}{\partial x}\right|_{x=0} = 0 & T_1 = T_{in} \\ \lambda\left.\frac{\partial T}{\partial x}\right|_{x=L} = h_{ex}(T - T_{ex}) & T_{ex} = 247 + 6.3\cos\left(\frac{2\pi}{24}(\tau - 15)\right) \end{cases} \quad (11)$$

Linear finite element equation of unsteady thermal conduction function can be derived by variable separation method. Supposed that indoor air temperature is constant, the heat flux, transferring through the interior surface is mainly used for heat storage at the beginning. A period later, the heat transfers from the interior surface to the exterior surface. While the thermal equilibrium is established, the exterior surface temperature reaches its maximum value. For the unsteady-state heat transfer of the envelope, it's interior surface thermal transfer strength is:

$$q_{in} = h_{in}(T_{in} - T_2(\tau)) \quad (12)$$

Where: q_{in} is thermal flux density through envelope internal surface, W/m^2; $T_2(\tau)$ is temperature of envelope interior surface, K.

the thermal flux density is made up of two parts, that is, thermal conduction strength of envelope material q_1 and thermal storage strength of envelope material q_2.

$$q_1 = \frac{T_2(\tau) - T_5(\tau)}{\sum_i^3 \delta_i / \lambda_i} = q_{ex} = h_{ex}(T_5(\tau) - T_{ex}(\tau)) \quad (13)$$

$$q_2 = \sum_1^3 \rho_i \cdot C_{pi} \cdot \delta_i \frac{dT(\tau)}{2d\tau} \quad (14)$$

Where: $\frac{dT(\tau)}{2d\tau}$ is average temperature change amount per unit time of the material, K/s

According to $q_{in} = q_1 + q_2$, Eq.(15) can be obtained.

$$T_2(\tau) = \frac{1 + h_{ex}\sum R}{h_{in} + h_{ex} + h_{in}h_{ex}\sum R} \times \left(\frac{h_{in}T_{in} + h_{ex}T_{ex} + h_{in}h_{ex}T_{in}\sum R}{1 + h_{ex}\sum R} - e^{-\frac{2(h_{in} + h_{ex} + h_{in}h_{ex}\sum R)}{(1 + h_{ex}\sum R)D}}\right) \quad (15)$$

Where: $D = \sum_1^n D_i$; $\sum R = \sum \delta_i / \lambda_i$.

Types and thermal parameters of VIPs composite envelope

The three envelopes are constructed according to the Figure 2. As the thermal resistances of stainless steel plate and steel plate are much smaller than that of thermal insulated materials, the stainless steel plate and steel plate are ignored in the simplified models and the following simulation. The core material of VIPs is super-fine glass fibre. And thermal properties parameters of thermal insulated materials are shown in Table 2.

Table 1. VIPs composite envelope structure.

NO.	Models	Composition (from inside to outside)
1	Interior adiabatic	Stainless steel plate and internal decoration +SCUFF panel + VIPs20mm+ PU150mm+steel plate, galvanized plate and outer decoration
2	Sandwich	Stainless steel plate and internal decoration + PU 75mm+ VIPs20mm+ PU 75mm+ steel plate, galvanized plate and outer decoration
3	Exterior adiabatic	Stainless steel plate and internal decoration + PU150mm+ VIPs 20mm +SCUFF panel+ steel plate, galvanized plate and outer decoration

Table 2. Thermal properties parameters of insulated materials.

Materials	Heat conductivity coefficient/ $W/(m\cdot K)$	Density/ kg/m^3	Specific heat capacity / $J/(kg\cdot K)$	Heat storage coefficient 24h / $W/(m^2\cdot K)$	Thermal inertia index/ D
PU	0.032	38	2475.2	28.06	/
VIPs	0.007	264	674.2	44.24	0.87

RESULT AND DISSCUSSION

Comparison of the damping factor and the delay time

As mentioned above, the damping factor and the delay time of a building envelope are all important parameters to characterize the interior surface temperature stability. The damping factor and the delay time of the three kind trailer house envelopes are collected in Table 3.

Table 3. The damping factor and the delay time of three trailer house envelopes.

NO.	Models	Thermal inertia index $\sum D$	The damping factor ν_0	The delay time ξ_0 / h
1	Interior adiabatic	7.69	289.35	11.47
2	Sandwich	6.81	270.16	10.64
3	Exterior adiabatic	6.35	265.52	9.41

The conclusion can be easily made from Table 3 that, the damping factor of model 1 is the largest one, followed by that of model 2, and that of model 3 is the smallest one. The change trends of delay time are the same with that of the damping factor. Under the same outdoor environment wave fluctuation condition, the bigger the damping factor is, the longer the delay time is, and the smaller the internal surface temperature fluctuation is, that means the excellent anti interference ability of outdoor environment temperature and good thermal stability. So the interior adiabatic model, namely the VIPs layer is closed to the interior in the envelope structure, is good for the internal surface temperature stability.

Interior surface temperature fluctuation

The interior surface temperature of trailer house envelope is one of the important factors of indoor thermal comfort study. It is also a vital factor of the moisture condensation on the surface of building internal wall surface, especially in cold region. The internal wall surface temperature fluctuations of three models under the same condition were numerically analyzed, and the simulation curves are exposed in Figure 4.

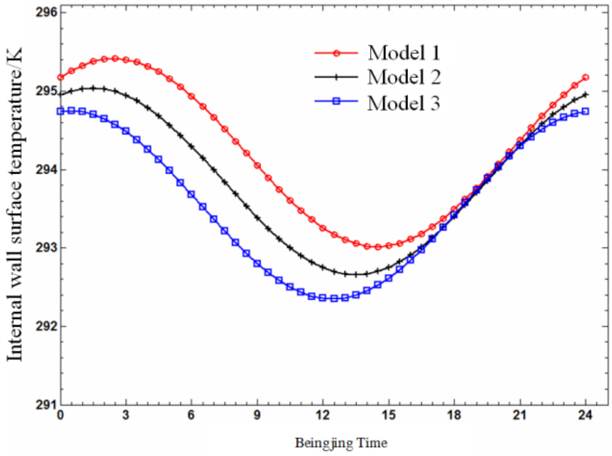


Fig. 4. Simulation curves of three internal wall surface temperatures.

All the internal wall surface temperatures kept pace with the external environment change and appeared in manner of sine waves, while the interior temperature was constant. As the thermal inertia index is the biggest of the three, the model 1 has the longest delay time and the smallest wave amplitude. The wave trough of the model 1, that is, 293.35K, appeared at about 14:00 in Beijing time. The wave troughs of models 2 and 3 are all a little lower that that of model 1, respectively 292.89K and 292.53K, even the difference with interior air temperature is not over 4K. Obviously, the internal wall surface of model 3 will easily moisture condense while the relative humidity is up to the dew point.

Taking the indoor thermal comfort for consideration, the mean internal wall surface temperature of model 1, a little high than that of models 2 and 3, is much closer to the interior constant temperature and can reduce the cold feeling of wall radiation.

Heat transfer capacity

For the unsteady thermal process of the trailer house envelopes, the initial input heat capacity Q_L is always not equal to the output heat capacity Q_R. As the heat storage capacity of the envelopes, resulting in the delay transfer of heat, and the fluctuation effect of external temperature, Q_L and Q_R cannot be equal to each other all the time, even $Q_R > Q_L$ at some moment. But for a cycle interval, the total input heat capacity should be approximate equal to the output one, that is, $\int_0^{24} Q_L d\tau \approx \int_0^{24} Q_R d\tau$ .The relate function can be expressed as:

$$\int_0^{24} Q_L d\tau = \int_0^{24} - h_{in} \left.\frac{\partial T}{\partial n}\right|_{x=0} \partial\tau = \int_0^{24} h_{in}(T_{in} - T_2(\tau))d\tau \quad (16)$$

Total heat transfer capacities in 24 hours of three envelopes are summarized in Table 4.

Table 4. Heat transfer capacity of three envelopes.

NO.	Models	Heat transfer quantity /24h / kJ/m^2
1	Interior adiabatic	1 277.86
2	Sandwich	1 390.61
3	Exterior adiabatic	1 443.02

The conclusion can be made from Table 4 that, energy transmission, that is, output heat capacity of model 1 is the smallest, followed by that of model 2, and the last is that of model 3. So, interior adiabatic structure is the best one for energy conservation.

Local thermal bridge effect

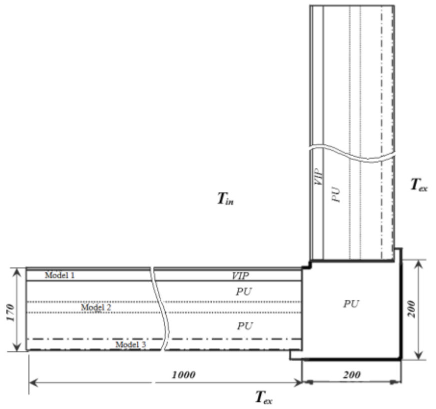
In order to enhance the trailer house envelopes strength, the steel components, such as beams, reinforcing ribs, crutches, etc. are always involved. But they can change the temperature distribution at their location, causing so called local thermal bridge. Under the cold region condition, the local internal surface temperature is much lower than that of main internal surface temperature, resulting in moisture condensation, even frost at the local space, reducing thermal comfort and causing potential danger. Although the area of the thermal bridge space is small, the heat loss is huge. As thermal bridge spots and types are various, the typical thermal bridge at the beam is selected in this research to simulation and discussion.

Three different configurations diagrams are shown in Fig. 5a, in which solid line means model 1, dotted line, model 2, dash line dot, model 3, and upper left corner area means indoor room boundary.

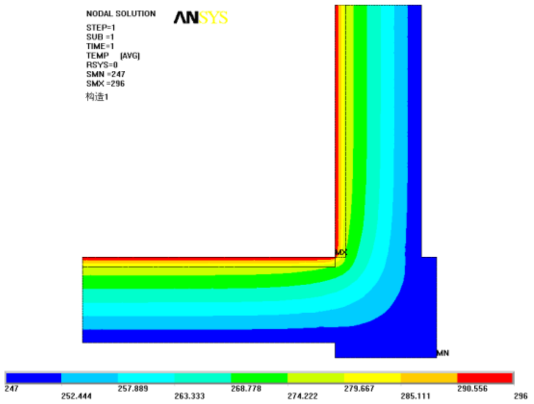
Combined with the third boundary condition, simulations for three models were exposed the temperature distribution and thermal bridge effect. And the results were shown in Figure 5b,c,d.

With the position of VIPs in envelopes shifting from the inside to the outside, the thermal bridge of the beam is becoming more and more significant. Isothermal trends of model 1 in Figure 5 (b) is gentle, and the local internal surface temperature, the minimum value 292.15K, even a little lower than the main internal surface temperature, is not beyond 4K difference with the interior temperature, that the code requires. Isothermal trends of model 2(shown in Figure 5(c)) and model 3(shown in Figure 5 (d)) are distorted, implying the thermal bridge effects are obviously. The lowest temperatures of model 2 and model 3, respectively, are 291.62K and 290.86K, all beyond 4K difference. So, under the large temperature difference condition, the interior adiabatic type of VIPs trailer house envelope is ideal for the reduction of energy loss and improvement of the interior thermal comfort.

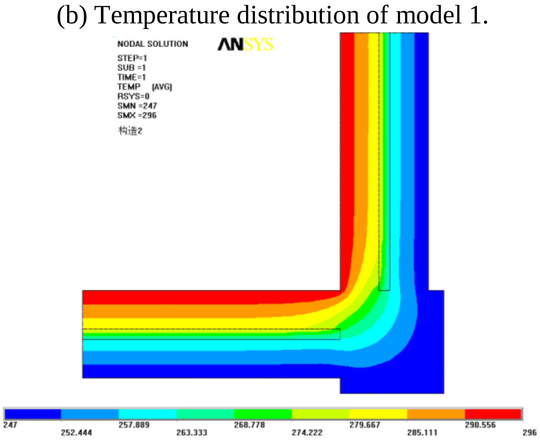
Taking the temperature distribution charts for consideration, the mean temperatures of the VIPs layers are also different. For a cycle period, the mean temperature of model 1 is 287K, is higher than that of model 2, 275K, also higher than that of model 3, 255K. However, VIPs' service life is influenced by ambient temperature. It is helpful to extend the service life if the surrounding temperature is close to the room temperature. So, the model 1 is ideal for the trailer house envelope.



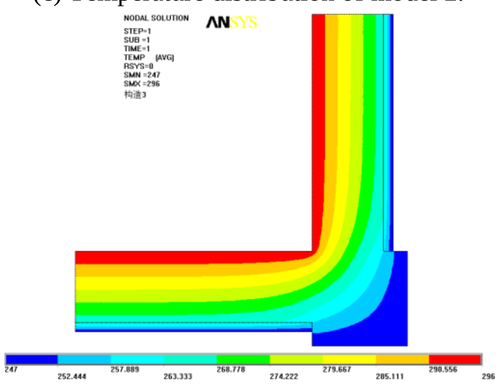
(a) Three different envelopes configurations.



(b) Temperature distribution of model 1.



(c) Temperature distribution of model 2.



(d) Temperature distribution of model 3.

Fig. 5. Three different envelopes configuration and temperature distribution diagram.

CONCLUSIONS

Three typical composite envelopes models for trailer house, by using VIPs, that is, interior adiabatic, sandwich, exterior adiabatic, are structured. And the thermal characteristics of the envelopes are theoretically compared under the cold region temperature condition.

(1) Combining with the three types and thermal performance in cold region, the damping factor, the delay time, the internal wall surface temperature vibration, and heat transfer flux are theoretically analyzed. Interior adiabatic model is superior to the others in energy conservation and indoor thermal comfort.

(2) The thermal bridge effects of three VIPs composite envelopes are simulated and theoretically analyzed under the unsteady condition. The conclusion can be gained that, the interior adiabatic type is excellent for energy conservation on thermal bridge regions and temperature difference decreasing between the internal wall surface temperature and indoor air temperature. Meanwhile, the interior adiabatic envelope can reduce radiation cold feeling, avoid local moisture condensation and improve thermal comfort index.

Acknowledgement: *This research is financially supported by the Natural Sciences Foundation of Shanghai, China (15ZR1419900). The authors would also like to render thankfulness to Mr. Yang Baotong from Yangzhou Tonglee Reefer Container Co., Ltd. for the kind help.*

REFERENCES

1. H.H. Wang, Y.Y. Zhuan, *Tongji University(Natural Sciences)*, **38**, 1641 (2010).
2. R. Baetens, B.P. Jelle, J.V. Thue, *Energy and Buildings*, **42**, 147 (2010).
3. M. Alam, H. Singh, *Applied Energy*, **88**, 3592 (2011)
4. J. Fricke, U. Heinemann, H.P. Ebert, *Vacuum*, **82**, 680 (2008).
5. J. Zhang, Z.L. Huang, *Harbin Engineering University*, **30**, 1356 (2009).
6. H.M. Li, W.L. Jin, *J. Building Struct.*, **25**, 93 (2004).
7. GB50189-2005, Design standard for energy efficiency of public buildings, China Building Industry Press, Beijing, 2005.
8. GB50176-1993, Code for thermal design of civil buildings, China Building Industry Press, Beijing, 1993.
9. CAN/CSA-Z240.2.1-1992, Canadian Standards Association Standards, *Structure Requirements for Mobile Homes*, Canada (in press), 1992.