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유한요소법을 이용한 벽체의 단열 성능 분석[*1]

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Finite Element Analysis of Adiabatic Properties for the Wall System in Wood Frame House[*1]

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要 約

본 연구에서는 경골 목조 주택(2×4 주택, 2×6 주택), 통나무 주택 및 콘크리트 주택(내단열, 중단열, 외단열) 벽체에 대하여 유한 요소 해석으로 단열 성능을 평가하였고, 표면 결로 현상을 분석하여 다음과 같은 결론을 얻었다.

1. 벽체의 단열 성능은 경량 골조 2×6를 사용한 주택이 가장 우수하였고, 경량 골조 2×4 주택, 통나무 주택, 콘크리트 주택의 순으로 감소하는 것으로 나타났다.
2. 콘크리트 벽체의 내단열, 중단열, 외단열의 벽체 구성법에 따른 단열 성능의 차이는 없었으며, 콘크리트 주택에서 단열재의 사용이 필수적이었다.
3. 내부 결로의 경우 콘크리트 벽체의 외단열이 가장 우수한 결로 예방성을 보였다. 이는 외부에 설치된 단열층이 외부의 낮은 온도를 차단해 벽체 전체의 온도를 높게 유지하기 때문이었다. 표면 결로는 모든 벽체에서 나타나지 않았지만, 실내 습도가 높아진다면 콘크리트 주택의 벽체에서 발생할 가능성이 가장 높았다.

본 연구는 벽체내의 단열 성능에 관하여만 분석을 하였고, 열전달 외에 축열성능 등에 관한 고려는 하지 않았으므로 추후에는 여러 가지 복합적인 열적 성능에 관한 연구가 수행되어야 하리라고 생각한다.

Keywords: Adiabatic property, finite element analysis, wood frame house, heat conductivity coefficient, dew condensation, insulation

1. INTRODUCTION

Wood construction has been taken a increasing interest domestically, which had been major in the U.S.A. and Japan. The reason is that wood construction serves a comfortable living environment with the better humidity control ability, the roomy house with strong enough thin walls, better adiabatic properties, good maintenance and easy reconstruction, endurance against the seismic and wind load compare to concrete building. And the interior is beautiful without special interior decoration, and the exterior is versatile. The most of domestic house was built by concrete, however, of which wall was thick because of the material weight, and

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the aging occurred easily. Therefore, wood construction is given increasing interest and study domestically.

Since the energy crisis at 1973, the interest about building adiabatic properties has been increased in order to reduce the heating and air conditioning energy which occupy 70 % of consumed energy at building. The good adiabatic properties are indispensible for building to control temperature. That is, the good adiabatic properties are required to lessen heating and air conditioning cost at any seasons (David *et al*, 1991).

The reduction of energy in building is accomplished by intercepting the heat loss through the walls, floors and ceilings efficiently. Therefore, the addition of insulation material has being increased for raising the adiabatic effect at walls, floors, and ceilings in the building after the energy crisis. On the other hand, the adiabatic properties of doors and windows were important at the point of view of the energy reduction. Kim(1991) reported that the insulation had been to use in the suitable shape and part, and installation method of insulation material had been to use properly for the correct insulation design and installation. And he reported that the study of materials and installation of outside insulation was required. Kim(1986) emphasized the importance of insulation installation and reported that adiabatic properties were increased with proper insulation installation.

To understand and solve the heat transfer problem of wall, it is needed to study the variated steps of wall temperature with several materials(David *et al,* 1987). Therefore, in the case of wood frame construction, the adiabatic properties of wall had to analyze the composite wall because the wall was composed of wood, insulation material, sheathing material, and finishing material.

The finite element analysis and finite difference analysis were used to the adiabatic property analysis of composite wall. But the finite difference analysis was limited the range and complicated the methods comparing to finite element analysis. So, the finite element analysis was used to analyse the adiabatic properties of composite wall in this study.

In this study, heat conductivity of the composite wall and materials of wood and concrete building walls were tested and analysed by the finite element analysis to find the energy efficient model. So, finding the heat conductivity of each composition material that compose of the wall can find the heat conductivity of composite wall. Consequently, these results will be contributed the energy reduction policy in later.

2. MATERIALS & METHODS

Adiabatic properties of the composite wall were analyzed by the two dimensional finite element method in order to study the influence of each composition material.

2.1 Measurement of heat conductivity coefficient

The heat conductivity coefficient of gypsum board, styrofoam, hem-fir, douglas-fir, and plywood were measured.

The heat conductivity of the composition materials of wood house wall were measured by the heat conductivity tester at Fire Insurers Laboratories of Korea. The method of measuring heat conductivity coefficient was based on the KS L9016, ASTM C518 and ISO DIS 8301. The heat conductivity coefficient was calculated by the heat flow, temperature difference at the specimen surface, heat flow area, and depth of specimen, when the temperature at upper and lower plate were equivalent. The test was executed at 20℃, the average temperature condition.

$$q = \lambda \cdot A \cdot \frac{\Delta T}{d}$$

where

q : *heat flow*
λ : heat conductivity coefficient
A : *heat flow area*
T : *temperature difference of specimen* ($T_h - T_c$)
d : *depth of specimen*
T_h : *temperature of upper plate*
T_c : *temperature of lower plate*

2.2 The FEM analysis

In this study, the adiabatic properties of wood frame house wall and concrete building wall were calculated from the heat conductivity coefficient of each material which was composed of wood construction and concrete building wall.

The governing differential equation for heat transfer through a composite wall is

$$kA \frac{d^2\phi}{dx^2} = 0$$

where

ϕ : known convection heat loss occurs from both surface.

The convection boundary condition was

$$kA \frac{d\phi}{dx} = hA(\phi_b - \phi_f) \; at \; x = 0$$

and

$$-kA \frac{d\phi}{dx} = hA(\phi_b - \phi_f) \; at \; x = H$$

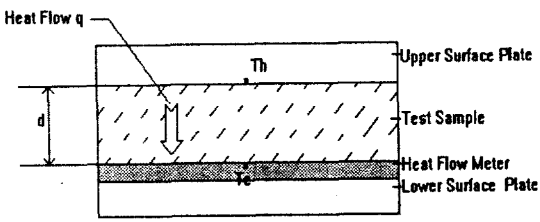

Fig. 1. The testing method of the heat conduction coefficient.

where k : heat conductivity coefficient (kW/cm-°K)
h : convection coefficient (kW/cm²-°K)

The element stiffness matrix was

$$[k^{(e)}] = [k^{(e)}D] + [k^{(e)}M_i] + [k^{(e)}M_j]$$

where $[k^{(e)}D]$: resulted from the shape function and heat conductivity coefficient
$[k^{(e)}M_i]$: resulted from the convection boundary condition at node i
$[k^{(e)}M_j]$: resulted from the convection boundary condition at node j.

The element force vector was

$$[f^{(e)}] = \begin{bmatrix} hAi\phi_f \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ hAi\phi_f \end{bmatrix}$$

where $\{f^{(e)}\}$, $[k^{(e)}M_i]$ and $[k^{(e)}M_j]$ was neglected when temperature was specified at both surfaces.

Using the upper governing equation, the temperature at each element node divided linear rectangular finite element in the wall was calculated. The algorithm of two dimensional finite element program was illustrated in Fig. 2.

2.3. Wall composition

The wall of light frame house was composed of the exterior siding, sheathing, insulation and gypsumboard, usually. The composition materials were chosen for the proper purpose of circumstance and temperature. The most popular insulation materials were glass fiber and urethane board in wood frame house. The exterior materials were used usually in water protected and preservatives, interior finish of wall and ceiling were used the gypsumboard, and the floor was used the hardwood flooring, generally.

The composition material and thickness were shown the following table 1. The walls selected

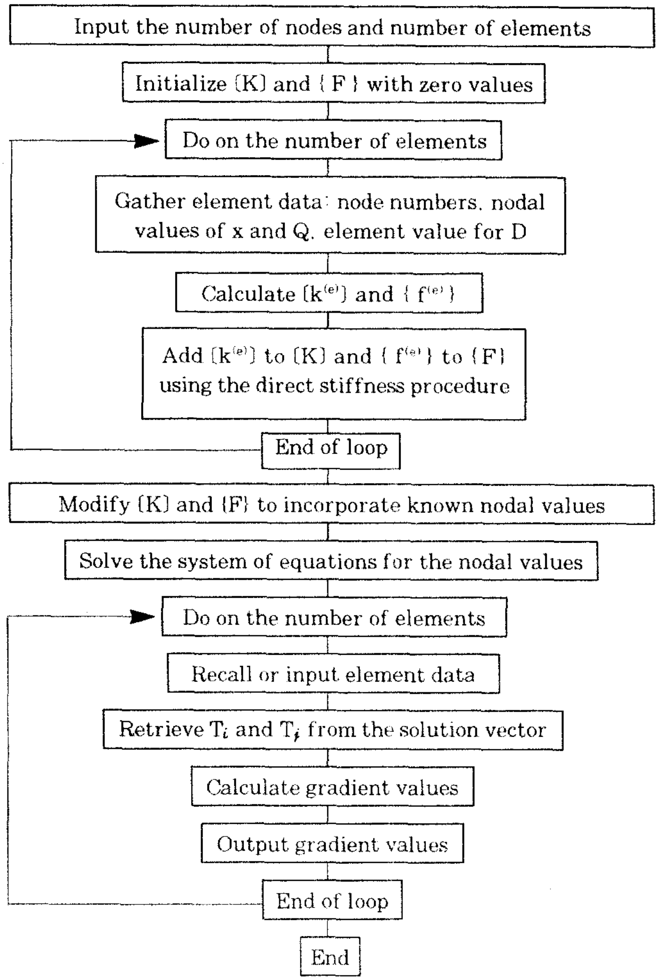

Fig. 2. Algorithm chart of the finite element program.

in this study were 2×4, 2×6 light frame wall and log house wall for wood construction and inside, center, outside insulated concrete building wall. The total thickness of wall were 13 cm for 2×4, 18 cm for 2×6, 16 cm for log house and 24 cm for concrete building wall.

3. RESULTS & DISCUSSIONS

3.1 The heat conductivity coefficient of wall composite materials

At average temperature condition 20℃, the heat conductivity coefficient of wall composition materials were shown in the following Table 2.

3.2 The analysing of the adiabatic properties of the wall

Because the adiabatic properties were important especially when the temperature of inner and outer home was different like summer and winter, the two season were selected to analyze the adiabatic properties. In summer, the temperature of outer was established at 35℃ and inner was 20℃. In winter, the temperature of

Table 1. The model of wall composition.

	Thickness of Composition materials(cm)					Total thickness (cm)
Light frame house (2×4)	Exterior Hem-fir(1)	Sheathing Plywood(1)	Insulation Glassfiber(10)	Gypsum board(1)		13
Light frame house (2×6)	Exterior Hem-fir(1)	Sheathing Plywood(2)	Insulation Glassfiber(14)	Gypsum board(1)		18
Log house	Exterior Hem-fir(7.5)	Insulation Styrofoam(1.0)	Interior Hem-fir(7.5)			16
Concrete (Inside insulation)	Exterior Building brick face(1)	Building brick(20)	Insulation Styrofoam(2) + Gypsumboard(1)			24
Concrete (Center insulation)	Exterior Building brick face(1)	Building brick(10)	Insulation Styrofoam(2)	Building brick(10)	Gypsumboard(1)	24
Concrete (Outside insulation)	Exterior Building brick face(1)	Insulation Styrofoam(2)	Building brick(20)	Gypsumboard(1)		24

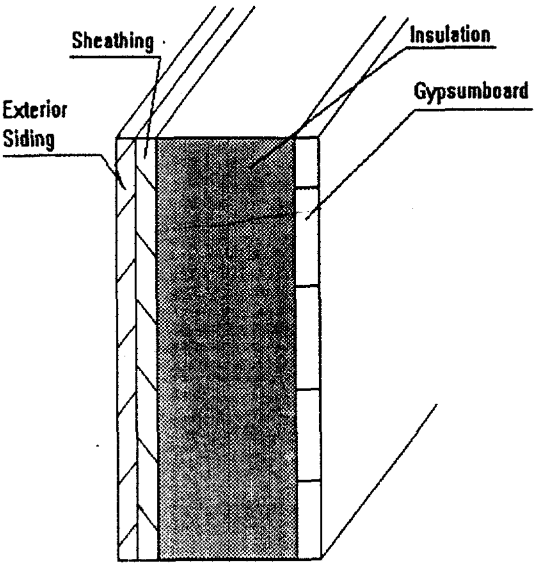

Fig. 3. Wall composition of the light frame house.

outer was established at -10℃ and inner was 20 ℃. The heat convection coefficient was established 0.001 W/cm^2 ℃ at 20 ℃, 0.0012 W/cm^2 ℃,

Table 2. Heat conductivity coefficient (W / m°K) for each material.

	Douglas-fir (interior)	Hem-fir (STUGA)	Plywood (sheathing)	Gypsum board	Styrofoam
Heat conductivity coefficient	0.090	0.096	0.091	0.146	0.034

at 35℃, and 0.0006 W/cm^2 ℃ at -10℃.

Although the inner temperature was the same at 20℃, the effective temperature was different in both season because of the temperature difference of inside wall surface. That is, because the temperature of inside wall surface over the 20℃ in summer and below in winter, one feels hot and cool. Therefore, it was ideal system for the wall system to decrease the heating and air conditioning energy that the high temperature of outside was transferred less in summer, and the low temperature in winter. And the superior adiabatic properties were the low temperature at inside surface and high temperature at outside surface of the wall in

Table 3. Temperature of the nodal point for each wall composition.

Light Frame House (2×4)	distance(cm)	0	1	2	12	13			
	summer	34.5	33.9	33.3	21.0	20.6			
	winter	-8.1	-6.9	-5.7	18.1	18.9			
Light Frame House (2×6)	distance(cm)	0	1	3		17	18		
	summer	34.6	34.2	33.3		20.7	20.4		
	winter	-8.6	-7.7	-5.9		18.6	19.1		
Log House	distance(cm)	0		7.5	8.5	16			
	summer	34.4		28.6	26.5	20.7			
	winter	-7.6		3.4	7.6	18.6			
Concrete House (inside insulation)	distance(cm)	0	1				21	23	24
	summer	33.9	33.8				30.0	22.2	21.3
	winter	-5.9	-5.7				1.5	18.6	17.5
Concrete House (center insulation)	distance(cm)	0	1		11	13		23	24
	summer	33.9	3.8		31.9	24.2		22.2	21.3
	winter	-5.9	-5.7		-2.1	12.3		15.9	17.5
Concrete House (outside insulation)	distance(cm)	0	1	3				23	24
	summer	33.9	33.8	26.1				22.2	21.3
	winter	-5.9	-5.7	8.8				15.9	17.5

summer, and the reverse in winter.

The temperature variation of wall was shown the following table 3 using the finite element method.

3.2.1 The analysis of adiabatic property in summer

The temperature variation curve of light frame house wall(2×4) was shown in Fig. 4. The right side of the graph was inside temperature and the other was outside temperature of the wall. The temperature of the inside surface was 20.6℃ and the outside was 34.5℃ in summer. The temperature variation curve of light frame house wall(2×6) was shown in Fig. 5. The temperature of the inside surface was 20.4 ℃ and the outside was 34.6℃. The temperature variation curve of log house was shown in Fig. 6. The temperature of the inside surface was

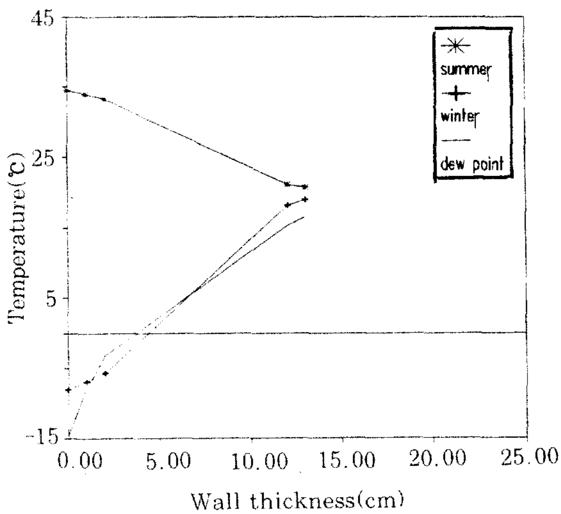

Fig. 4. Temperature variation in light frame wall (2×4).

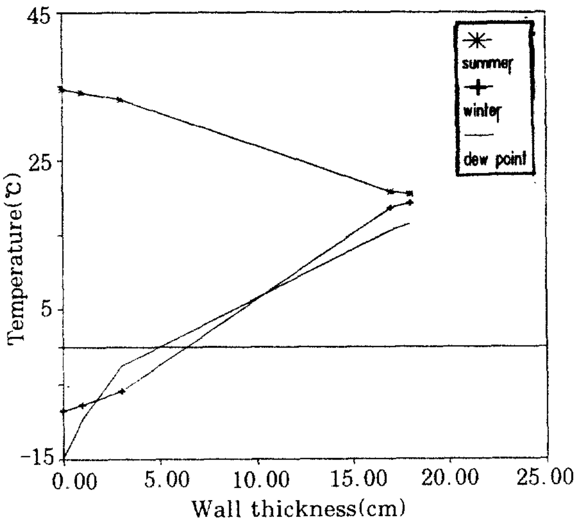

Fig. 5. Temperature variation in light frame wall (2×6).

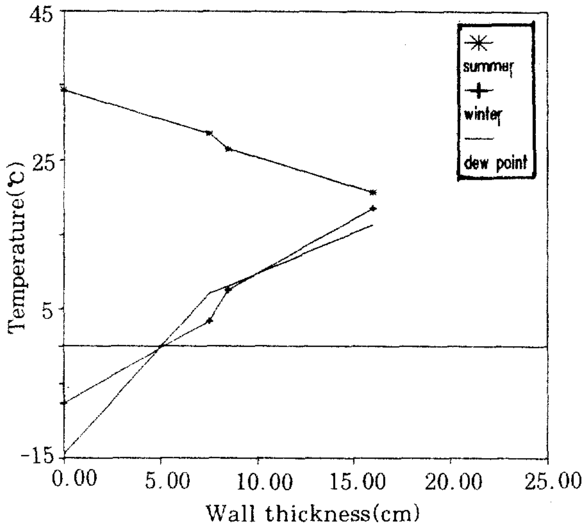

Fig. 6. Temperature variation in log house wall.

20.7℃ and the outside was 34.4℃. In the case of wood house. the temperature difference of inside surface was 0.2~0.3℃. and outside surface was 0.1~0.2℃. Therefore there wasn' t significantly different in the wooden house wall for the adiabatic properties in summer.

In the concrete building wall. the styrofoam was used the insulation material. and it was

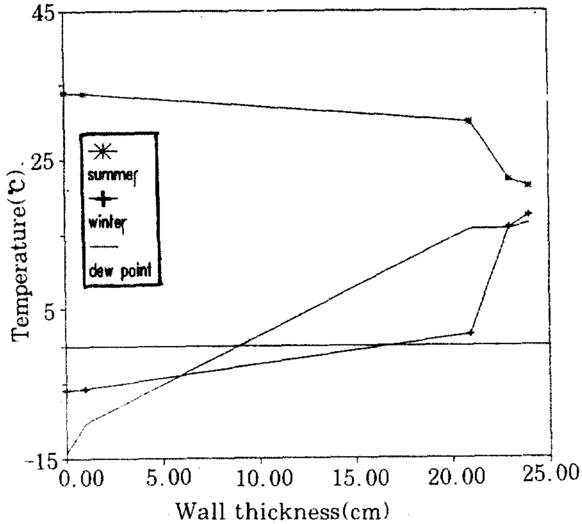

Fig. 7. Temperature variation in concrete wall (insulation at inside).

classified to insulate at inside. center. and outside. The concrete building was installed the exterior building brick for exterior. and gypsumboard for interior. The simulation condition was the same at wooden house. The temperature variation curve of concrete wall at inside insulation was shown in Fig. 7. The temperature of the inside surface was 21.3 ℃ and the outside was 33.9 ℃ in summer.

In the concrete wall of center insulation. the insulation was located between the building brick. The temperature variation curve of concrete wall at center insulation was shown in Fig. 8. The temperature of the inside surface was 21.3 ℃ and the outside was 33.9 ℃ in summer the same as the inside insulation.

In the concrete wall of outside insulation. the insulation material was located out of the building brick. The temperature variation curve of concrete wall at outside insulation was shown in Fig. 9. The temperature of the inside surface was 21.3 ℃ and the outside was 33.9 ℃ in summer the same as the inside insulation. Therefore. there was no difference the adiabatic property with location of the insulation mater-

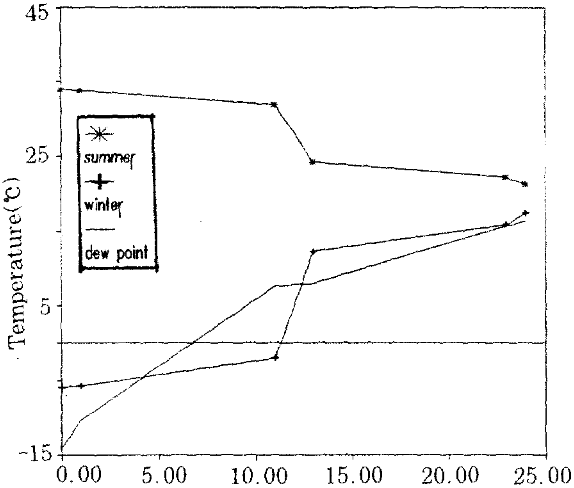

Fig. 8. Temperature variation in concrete wall (insulation at center).

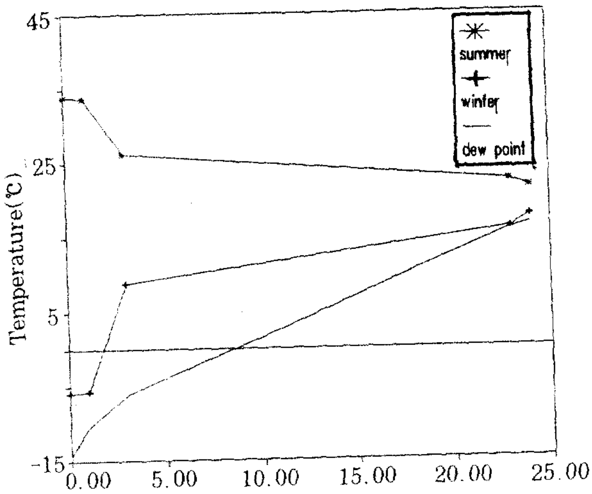

Fig. 9. Temperature variation in concrete wall (insulation at outside).

ial in concrete building wall.

In each wall system, the inside surface temperature was higher than the room temperature about 0.5 ℃ in wood frame house wall, 0.7 ℃ in log house wall, and 1.3 ℃ in concrete building wall besides of insulation location. Therefore, because the effective temperature in wooden house was lower than concrete building in summer, one feel more cool in wooden house. And, the outside surface temperature was lower than the air about 0.4 ℃ in wood frame house, 0.6 ℃ in log house, and 1.2 ℃ in concrete building wall. Therefore the air conditioning energy of the wooden house were lower than the concrete building in spite of the wall thickness.

3.2.2 The adiabatic property analysis in winter

The temperature of the inside surface was 18.9 ℃ and the outside was −8.1℃ in the 2×4 light frame house wall. The temperature of the inside surface was 19.1 ℃ and the outside was −8.6℃ in the 2×6 light frame house wall. The temperature of the inside surface was 18.6 ℃ and the outside was −7.6℃ in the log house wall. In the case of wooden house, the temperature difference of inside surface was 0.5 ~ 1.0 ℃ and outside surface was 1.0 ~ 0.5℃. Therefore there wasn' t significantly different in the wooden house wall for the adiabatic properties.

The temperature of the inside surface was 17.5℃ and the outside was −5.9℃ in the concrete building wall.

In each wall system, the inside surface temperature was lower than the room temperature about 1.0℃ in wood frame house wall, 1.4℃ in log house wall, and 2.5℃ in concrete building wall besides of insulation location. Therefore, because the effective temperature in wooden house was higher than concrete building in winter, one feel more warm in the wooden house. Therefore the heating energy of the wooden house was lower than the concrete building in spite of the wall thickness. Consequently, considering the heat transfer characteristic of the investigated wall, the energy saving capacity was superior to wooden house.

3.3 The analysis of the dew condensation of the walls

The dew condensation was caused the great problems in the home. It was classified the surface dew condensation and inner dew condensation by occurred location. The surface dew condensation was the phenomenon that the vapor was changed to the dew when the surface temperature was lower than the dew point temperature. And the inner dew condensation was the phenomenon that the dew condensation was occurred when the inner temperature of wall was lower than the dew point temperature. Therefore, in this study, the surface dew condensation and inner dew condensation was analysed in the wood frame house, log house, and concrete building wall. To calculate the dew point temperature in winter, the average humidity was assumed to 70 %, and the average room humidity was assumed to 80 %(Jung, 1989). The dew point temperature was calculated the following equation(Christen, 1972).

$$T_d = \frac{1,000}{(1000/T) + [\log(p_0/p)] / 2.26}$$

where T_d : dew point temperature
T : absolute temperature
p_0 : saturated vapor pressure at T
p : vapor pressure

The result of dew point temperature was shown in the fig. 4 ~ 10 with dashed line. The surface dew condensation was not occurred in any wall type. But the inner wall dew condensation was occurred differently at the each wall type and location of insulation layer.

In the case of light frame house(2×4), the dew condensation can occurred at the 2 ~ 7 cm from the exterior surface, from sheathing material to insulation layer. The maximum difference of dew point and wall temperature was 3 ℃, and it was occurred at boundary of the layer between the sheathing and insulation material. In the case of light frame house(2×6), the dew condensation can occurred at the 2 ~11 cm from the exterior surface, from sheathing material to insulation layer. The maximum difference of dew point and wall temperature was 4℃, and it was occurred at boundary of the layer between the sheathing and insulation material, the same as 2×4. In the case of log house, the dew condensation can occurred at the 5~10 cm from the exterior surface, inside and outside part of the insulation layer. The maximum difference of dew point and wall temperature was 5℃, and it was occurred at between outside log and insulation material.

In the case of concrete building wall, the inner dew condensation can occurred at the inside and center insulation. The dew condensation can occurred at the 6~22 cm in inside insulation, the maximum temperature difference was 15℃ at between the building brick and insulation material. The inner dew condensation damage would be the largest at inside insulation wall because the maximum temperature difference was the highest among the analysed case. The dew condensation can occurred at the 4~13 cm in center insulation, the maximum temperature difference was 6℃ at between the building brick and insulation material.

The wall composition to protect dew condensation effectively was the outside insulated concrete building wall, because the insulation layer can be protect to transfer outside low temperature.

The surface dew condensation was not occurred in any wall system, but the possibility would be larger in concrete building wall than wooden house wall.

4. CONCLUSIONS

The adiabatic properties and surface dew condensation of light frame wall(2×4, 2×6), log house wall and concrete wall were estimated. The obtained results are as follows:

1. In the adiabatic properties of walls, light frame house wall(2×6) showed the highest efficiency, light frame wall(2×4) and log

house wall were ranked high in efficiency.

2. The adiabatic properties of wall composition type had no difference in inside, center and outside insulation of concrete building wall. And the use of insulation material was an indispensable condition to concrete wall system.
3. For the inner dew condensation, the outside insulation of concrete wall was superior to any other wall type, because of keeping the high temperature of wall by insulation layer installed outside. Though the surface dew condensation did not occurred in any walls, the surface dew condensation occurred easily in concrete house wall with increasing room humidity.

This study analysed adiabatic properties of the wall system using only heat transfer. The study including the accumulated heat in the wall and other properties should be executed furthermore.

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