WINTER THERMAL IMPROVEMENT OF A TRADITIONAL HOUSE IN NEPAL

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ABSTRACT

An indoor thermal simulation was conducted in a traditional house in a mountain area of Nepal for the purpose of thermal improvement in winter and saving firewood. The results are as follows:

1) The simulation method used in the present research can be used to predict the indoor environment of various traditional houses and to determine optimal thermal improvements.

2) When firewood consumption is reduced by 60\% in the “Integrated improved” model, nighttime indoor air temperature was 1.0 to 4.0K higher than with the “Base model”. This shows that closing openings (doors, windows) to make the building airtight, and insulation of the roof are highly effective for thermal improvement and saving firewood.

INTRODUCTION

The aim of the present research is to investigate the effect of structural improvements on the thermal performance of traditional housing in a mountain area of Nepal. Prior to the present study, the thermal environment and the consumption of firewood in summer and winter were evaluated (Rijal et al., 2001, 2002, 2003). From this research, the following problems can be seen to occur in winter:

1) A large rise in the kitchen temperature from burning firewood in the open-hearth;

2) The nighttime air temperature of the attic room is below the outdoor air temperature, due to heat loss through radiation from the slate roof. Residents sleep in temperatures close to outdoor temperatures, which can have a negative effect on residents’ health (see note 1). Therefore an increase in nighttime air temperature is desirable (see note 2);

3) Residents experience discomfort on the earthen floor, where the surface temperature is very low;

4) The forest area is decreasing due to unplanned/unmanaged firewood harvesting. The demand for firewood must be reduced by improving the design and thermal performance of houses.

Research into traditional housing using thermal simulation has been carried out in Japan (Uran et al., 1987), China (Wang et al., 2002), Thailand (Tantisavrasdi et al., 2001) and Sri Lanka (Ratnaweera et al., 1996). However, research into the effects of housing improvements on firewood consumption has not been seen. In Nepal, 76\% of the energy supply comes from firewood (H.M.G. of Nepal, 2002), and the amount of firewood consumption is directly related to the thermal environment in houses.

In this research, a traditional house in the mountain area of Nepal (Rijal et al., 2001) in winter was simulated before and after structural improvements for the following purposes:

1) To verify the accuracy of the “Base model” using measured indoor air temperature to analyze the effect of the improvements.

2) To determine the effect of the thermal improvements such as roof, floor, and wall insulation, and the air tightness of openings and gaps.

3) To evaluate the reduction of firewood consumption due to the thermal improvements.

OUTLINE OF SIMULATION

The simulation code was developed by modifying HASP/ACL (Matsuo et al., 1980), a Japanese heating/cooling load calculation program where the algorithm is based on the internationally-used response factor method, adding two major parts: 1) calculation of the natural ventilation rates for a building with multiple compartments; and, 2) calculation of heating and cooling loads, considering simultaneous heat and moisture flow in the building and the existing materials in components (Yoshida et al., 2002). The time-step of the simulation is one hour. The initial influence of the earth floor and the thick walls was excluded by running the simulation over a period of 3 weeks.
Figure 1 Simulation "Model I" (unit: mm)

(a) Plan of 1F

(b) Section of X-X

Figure 2 Construction of the wall (unit: mm)

(i) Wall

(a) "Wall A"

(b) "Wall B"

(c) "Wall C"

Figure 3 Construction of the earth floor, ceiling and roof (unit: mm)

(a) Earth floor (1F)

(b) Ceiling

(c) Roof
“Base model”

To predict the indoor air temperature and the amount of ventilation, a “Base model” was built (Figures 1 to 3). The total floor area was 54.5 m², and each floor had a single room. 1F has an earthen floor with a 19 m² floor area, and thick walls. The surface temperature of the underground side was assumed to be the average indoor air temperature. Building structures, such as the pillars, beams, and rafters were input as a heat reservoir. Because of the small temperature difference between the semi-open space and the outdoors, the semi-open space was considered as part of the outdoors in this model.

The wall structure is shown in Figure 2(r). The wall had to be analyzed for three-dimensional heat flow; however, to approximate the one-dimensional heat flow, three kinds of walls (A, B & C) were proposed. “Wall A” was structurally closest to the original wall. “Wall B and C” were compared with “Wall A”.

Simulation “Model I” had only one zone in each room (Figure 1) and it no temperature distribution was assumed in each room, using one node to express the room. However, temperature distributions did exist, even within a single room, and two kinds of simulations, “Model II & III”, with virtually divided rooms were used for the investigation. In “Model II”, simulations 2F and 3F were divided horizontally into two rooms, while in the “Model III”, 2F was similar to that in “Model II”, and 3F was divided in half horizontally and vertically into four rooms. The partition wall used to divide the space was 5 mm thick plywood with an opening 1/3 the size of the partition wall. The size of the opening was confirmed to allow sufficient airflow.

Openings

Doors at the south end of 1F and 2F were left partially or fully open when firewood was being burned, and were closed at night. The length of time this door was left open was noted and a mean figure was used for the simulations. 1F contained one window and one smoke hole, 2F had one window, and 3F had six windows. These windows did not have panes, and therefore the winter nighttime indoor air temperature was very low. The staircase landings on each floor were open, and a large amount of air, warmed by burning firewood in 1F rises to the floors above.

In addition, visible gaps exist 1) between the frame and the joint of the doors; 2) between the top of the wall and the roof; and, 3) in the slate roof. These gaps were input as openings in the model. The coefficient of discharge of the openings was assumed to be 0.6, as most openings are sharp-edged configurations. The wooden door and window frames were far from airtight and the window frame leakage constant was 12.9, when closed. The thermal performance of the earthen floor, the wall, and the roof was verified by reducing the amount of ventilation, closing the openings at night. The measured wind direction was classified in 16 wind directions, and the wind pressure coefficient of the openings (Katsuta et al., 1962) and gable roof was taken from previous research. For the gable roof, the wind pressure coefficient of “Akabayashi” (17 to 20° roof angle, Akabayashi et al., 1994) and “Faber” (45° roof angle, Faber et al., 1952) were compared.

Heating value

Firewood consumption in one week was recorded and the average consumption was 18.4 kg/day. The mean heating value of the firewood used in the simulation was 16.6 MJ/kg (number of samples of woods=42, mean moisture content=13%, Miura et al., 1933). The total heat gain from per person was estimated at 119 W, as most residents were working.

Meteorological data

The meteorological data used in the simulation were outdoor air temperature, absolute humidity, normal direct solar radiation, horizontal sky radiation, horizontal effective radiation, wind direction and wind velocity. These were measured from December 12th to 18th, 2000 (Rijal et al., 2002). Normal direct solar radiation and horizontal sky radiation were calculated from global solar radiation using the equation of Udagawa et al. (1978), and horizontal effective radiation was calculated using Brunt’s formula (Brunt, 1932, Matsuo et al., 1980).

“IMPROVED MODEL”

To improve indoor air temperature and to reduce firewood consumption, 3 kinds of sealants were used to make the openings airtight (improved model “A” to “C”); 3 kinds of insulation were used in the roof, floor and walls (improved model “D” to “F”); and 2 integrated models were used. These “improved models” were constructed in January 2003 (see note 3). Instead of locally-available insulation materials (straw and thatch), which are easily damaged by rats and cockroaches, wooden boarding was used for insulation. This boarding is not included in the general definition of insulation, however, it is referred to as insulation for the purposes of the present research.

“A”: Reduction of the open area above staircase

To control the draught from the lower floor to the upper floor, the area above the staircase was left open for 50% of the period of firewood combustion (6:00 to 21:00) and closed by a wooden board at other times. The effects of the board installation
were examined in the following situations: reduction of the area at the top of the staircase on 1F (A1), 2F (A2), and on 1F & 2F (A3).

“B”: Adjustment of opening
To reduce heat loss, glass was installed in the window. The use of the window was observed, and was estimated to be open for 20% of the daytime hours and closed at night. Doors and the smoke hole were open for 50% of the period of firewood combustion and closed at other times. These figures were used in the simulation.

“C”: Reduction of the gap area
To prevent draughts, the area of cavities was reduced to 1/10 (surrounding the door), 1/50 (between the wall and roof) and 1/100 (roof) of the “Base model”. To achieve this, the frame and the door were made of cypress (which has strong resistance to warping), the gap between the wall and roof was filled with sticky soil, and the roof was insulated with pine board. Furthermore, to improve the air-tightness of the roof, vinyl sheeting was placed over the wooden boards, and the spaces between these boards were covered from inside by smaller boards (Figure 3(c)).

“D”: Insulation of the roof
To improve the insulation of the roof, pine board (30mm) was installed on the interior surface of the roof (Figure 3(c)). Pine was used because it is locally available, light in weight and easy to use. The coefficient of heat transmission of the roof is 3.7 W/(m².K) in the “Base model” and 2.3 W/(m².K) in the improved “D”.

“E”: Insulation of the earthen floor
As mentioned in the introduction, residents suffer from an extremely cold earthen floor underfoot. To remedy this problem, cypress board (30mm) was installed on the earthen floor (Figure 3(a)). Cypress was chosen for its strength and water-resistance.

“F”: Insulation of the wall
The surface of the existing walls was made of clay, which, in contact with clothes, results in stains, as well as discomfort due to heat loss. To remedy this, pine boards (30 mm) were installed on the inner walls of 1F from floor level to a height of 950 mm (Figure 2(i)). The coefficient of heat transmission of the wall is 1.2 W/(m².K) in the “Base model” and 1.0 W/(m².K) in the Improved “F”.

“Integrated improved”
The improvements described above were combined, “Integrated improved”, and investigated to evaluate the overall effect. To determine the effect of firewood reduction on the “Integrated improved” model, firewood consumption was reduced by 60% every hour, referred to as “Reduced firewood consumption”.

THERMAL ENVIRONMENT OF THE “BASE MODEL”
The accuracy of the “Base model” was verified to evaluate the thermal environment generated by the “Improved model”. The mean indoor air temperature difference between the simulation and actual measurement (ΔT), Root Mean Square Error of the measured and simulated indoor air temperature (RMSE), and air changes per hour (ACH) were used for the evaluation. If there is no difference in temperature (ΔT), the difference in the maximum indoor air temperature is used for the evaluation. In the ACH calculation for 2F and 3F, not only the inflow of the fresh air from outdoors, but also the amount of ventilation from 1F or other rooms was also added because the present research focuses on thermal environment.

Selection of wall and simulation model
To select the suitable “Base model”, 3 kinds of walls and 3 kinds of space-divided models were investigated. The indoor air temperature, ΔT, RMSE and ACH are shown in Table 1.

(1) Walls
The wall type was selected by comparing the proposed walls. In the “Present condition” of the opening, differences in ΔT and RMSE for “Wall A, B & C” were within 0.1K, ie. “Walls A, B & C” showed a negligible difference. This is because the daily mean ACH was 42 to 73 and the indoor air temperature is highly affected by the ventilation rate. When the opening is “Closed at night”, the night mean ACH decreased by 16 to 44. Under this condition, the differences in ΔT and RMSE for “Walls A, B & C” were within 0.2K, a negligible difference. For “Walls A, B & C”, ΔT and RMSE showed negligible differences in both the open and closed positions, therefore “Wall A” was used for all further case studies.

(2) Space division of room
To select the simulation model, “Models I, II & III” were compared. For “Model I”, ΔT was −1.4K (1F), +0.3K (2F) and +1.4K (3F). RMSE for “Model I” was 2.7K (1F), 1.3K (2F) and 1.7K (3F). The temperature distribution was very high on 1F because of firewood combustion for cooking and heating, and it is difficult to predict indoor air temperature precisely. There is no firewood combustion on 2F and 3F, and the distribution of
### Table 1

The $\Delta T$, RMSE and $\text{ACH}$ of the each model

<table>
<thead>
<tr>
<th>Items</th>
<th>Model</th>
<th>$\Delta T = \bar{T}_a - \bar{T}_b$ [K] (2000/12/12~18)</th>
<th>RMSE [K] (2000/12/12~18)</th>
<th>$\text{ACH}$ (2000/12/13)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1F</td>
<td>2F</td>
<td>3F</td>
</tr>
<tr>
<td>$\bar{T}_a$ °C</td>
<td></td>
<td>22.0</td>
<td>16.8</td>
<td>14.2</td>
</tr>
<tr>
<td>Wall</td>
<td></td>
<td>-1.4</td>
<td>0.3</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2</td>
<td>3.8</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>-1.4</td>
<td>0.3</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2</td>
<td>3.8</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>-1.5</td>
<td>0.2</td>
<td>1.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2</td>
<td>3.6</td>
<td>3.3</td>
</tr>
<tr>
<td>Space division of room</td>
<td></td>
<td>-1.4</td>
<td>0.3</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-1.4</td>
<td>0.6</td>
<td>2.3</td>
</tr>
<tr>
<td></td>
<td>II</td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>III</td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Wind pressure coefficient</td>
<td></td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Akabayashi</td>
<td>-1.2</td>
<td>-0.4</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Faber</td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td>Vertical distribution of wind</td>
<td></td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>with cosider</td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>without cosider</td>
<td>-1.4</td>
<td>-0.6</td>
<td>1.4</td>
</tr>
</tbody>
</table>

$\bar{T}_a$ & $\bar{T}_b$: Measured and simulated indoor air temperature, "---": "Closed at night"

indoor air temperature can be assumed to be normal. “Model II” was investigated to predict precise indoor air temperatures on 2F and 3F. $\Delta T$ for 2F in “Model II” was 0.9K, lower than for “Model I”. RMSE for “Model II” was 0.2K lower than for “Model I”. There was no difference in either $\Delta T$ or RMSE on 3F. “Model III” was investigated the vertical distribution of air temperature. Both $\Delta T$ and RMSE for “Model III” were 0.9K, larger than those for “Model II”, a large margin of error. Therefore, “Model II” was used in the other case studies.

### Selection of the wind pressure coefficient and the vertical distribution of wind

To select a suitable “Base model”, the wind pressure coefficient and the vertical distribution of wind were investigated.

**1) Wind pressure coefficient**

The wind pressure coefficient of the gable roof was compared with the wind pressure coefficients of Akabayashi and Faber. This was carried out on 3F, from which the roof could best be observed. There was no difference in $\Delta T$ and RMSE using the wind pressure coefficients of Akabayashi and Faber. Using Faber’s wind pressure coefficient, inflow through the opening was observed and the maximum indoor air temperature in nighttime was 0.5K lower than using the Akabayashi coefficient. Both wind pressure coefficients showed a negligible difference. The Akabayashi wind pressure coefficient was chosen for other case studies because it can be used for almost all wind directions.

**2) Vertical distribution of wind**

The vertical distribution of wind was compared for 3F, where the effect can be greater. Both $\Delta T$ and RMSE were 0.1K, smaller than when the vertical wind distribution was not taken into account. Although this difference was negligible, the vertical distribution of wind was included in other case studies.

### Characteristics of the “Base model”

The “Base model” variables, (1) “Wall A”, (2) “Model II”, (3) wind pressure coefficient of “Akabayashi” and (4) consideration of the vertical distribution of wind were selected based on the verification results. The $\Delta T$ and RMSE are shown in Table 2. The profile of the indoor air temperature of the “Base model” was similar to the measured value. The $\Delta T$ was +0.5K (1F), −0.3K (2F) and +1.3K (3F). The RMSE was 1.0 to 1.8K. Outside the period of firewood consumption, the simulated and measured values were well matched and the accuracy of prediction is high. The following characteristics were observed for the “Base model” with respect to natural ventilation:

1) $\text{ACH}$ was higher during the day than at night. Possible factors influencing $\text{ACH}$ are external wind velocity (stronger in daytime), wind direction (north at night), the position of the smoke hole (on the

### Table 2

Result of the “Base model” (2000/12/13)

<table>
<thead>
<tr>
<th>Items</th>
<th>$\bar{T}_a$ °C</th>
<th>$\Delta T = \bar{T}_a - \bar{T}_b$ [K]</th>
<th>RMSE [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Daily</td>
<td>Day</td>
<td>Night</td>
</tr>
<tr>
<td>1F</td>
<td>19.8</td>
<td>21.6</td>
<td>18.1</td>
</tr>
<tr>
<td>2F</td>
<td>15.8</td>
<td>16.3</td>
<td>15.3</td>
</tr>
<tr>
<td>3F</td>
<td>15.3</td>
<td>16.0</td>
<td>14.6</td>
</tr>
</tbody>
</table>

$\bar{T}_a$ & $\bar{T}_b$: Simulated & measured indoor air temperature, Day: 7:00 to 18:00, Night: 0:00 to 6:00, 19:00 to 24:00
Table 3
The \( \Delta T \), RMSE and ACH of the each model (nighttime)

<table>
<thead>
<tr>
<th>Items (2000/12/13)</th>
<th>( T_i - T_s ) [K]</th>
<th>( \nu_i - \nu_s ) [ACH]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1F</td>
<td>2F</td>
</tr>
<tr>
<td>Base model (( T_i \ [{\degree}C], \nu_s \ ))</td>
<td>18.1</td>
<td>15.3</td>
</tr>
<tr>
<td>(A1) Reduction of the open area above staircase (1F)</td>
<td>5.1</td>
<td>-0.1</td>
</tr>
<tr>
<td>(A2) Reduction of the open area above staircase (2F)</td>
<td>2.1</td>
<td>2.7</td>
</tr>
<tr>
<td>(A3) Reduction of the open area above staircase (1F &amp; 2F)</td>
<td>5.7</td>
<td>2.1</td>
</tr>
<tr>
<td>(B) Adjustment of the opening</td>
<td>7.2</td>
<td>3.2</td>
</tr>
<tr>
<td>(C) Reduction of the gap area</td>
<td>0.8</td>
<td>1.6</td>
</tr>
<tr>
<td>(D) Insulation of the roof</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>(E) Insulation of the earth floor</td>
<td>-0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>(F) Insulation of the wall</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>(G1) Integrated improved</td>
<td>12.7</td>
<td>9.5</td>
</tr>
<tr>
<td>(G2) Reduced firewood consumption</td>
<td>3.9</td>
<td>4.0</td>
</tr>
</tbody>
</table>

\( T_i \) & \( T_s \) : Indoor air temperature of the Base & Improved model, \( \nu_i \) & \( \nu_s \) : ACH of the Base & Improved model

2) The ACH was 19 to 69 (1F), 37 to 145 (2F) and 47 to 211 (3F), as large as that for the upper floor. On 3F, there are many inflows of air, e.g., 6 windows, the gap in the roof, etc. The results show that the indoor air temperature of the traditional house was highly affected by natural ventilation. The values for ACH, which were very high, were compared with results from previous research to check whether they are valid. In the traditional houses of Kyushu, Japan (volume of room = 280 m\(^2\)), the ventilation rate was 14 ACH for a tatami mat room and 31 ACH for earthen rooms, when the door was opened in daytime (12:00, Urano et al., 1987). The results were close to those of the “Base model” (1F) because of a smaller number of openings.

THERMAL ENVIRONMENT OF THE “IMPROVED MODEL”

The “Base model” and the “Improved model” were compared to determine the effect of the improvements on indoor air temperature and firewood consumption. The mean indoor air temperature and the ACH at night of the “Base model” and the “Improved model” are shown in Table 3.

“A”: Reduction of the open area above staircase

The improved indoor air temperature (\( T_i \)) of the improved “A1” showed a difference of +5.1K (1F), -0.1K (2F), and -0.7K (3F). The \( T_i \) of 2F and 3F decreased because the amount of warm air flowing from the lower floors to the upper floor was less than that in the “Base model”. The \( T_i \) of the improved “A2” showed differences of +2.1K (1F), +2.7K (2F) and -1.2K (3F). It can be said that the improved “A2”, which improved both 1F and 2F, is more effective than the improved “A1”. The \( T_i \) of the improved “A3” showed differences of +5.7K (1F), +2.1K (2F) and -1.2K (3F). Overall, “A3” showed the greatest improvements and this model was used as “Integrated improved”.

“B”: Adjustment of opening

To improve the air-tightness, the effect of the improved “B” was simulated. \( T_i \) of the improved “B” were 7.2K (1F), 3.2K (2F) and 0.1K (3F), higher than the “Base model”. The effect of the improvement is as large as that for 1F.

“C”: Reduction of the gap area

To prevent droughts, the effect of the improved “C” was simulated. \( T_i \) of the improved “C” were 0.8K (1F), 1.6K (2F) and 2.6K (3F), higher than that of the “Base model”. The effect of this improvement is greater for the upper floors, ACH for 3F decreased by approximately 50%.

“D”: Insulation of roof

The \( T_i \) of the improved “D” was 0.2 K (3F), higher than the “Base model” in the “Present condition” of the opening. When the openings were “Closed at night”, the insulating effect was increased by 0.9K.

“E & F”: Insulation of the earthen floor and wall

\( T_i \) of improved “E & F” were almost identical to the “Base model”, when the opening was in the “Present Condition” and when “Closed at night”. The cooling effect of conduction (contact heat loss) will be investigated in the future.

“Integrated improved”

To clarify the overall effect, all improvements (“A” to “E”) were combined and simulated. \( T_i \) of the
“Integrated improved” were 12.7K (1F), 9.5K (2F) and 4.4K (3F), higher than the “Base model”. The effects of the improvements were as large as that for 1F. On 1F and 2F in particular, the effects of the improvements were very high, resulting in an uncomfortable thermal environment. This is investigated from the viewpoint of energy savings in the next section.

“Reduced firewood consumption”

To achieve a comfortable thermal environment and energy savings, “Reduced firewood consumption” was simulated. The reduction of firewood consumption was investigated by setting the goal of maintaining daytime indoor air temperature at the present level and increasing the nighttime average indoor air temperature above 15°C, which could be achieved with a 60% reduction in maximum firewood consumption.

The temperature setting of 15°C was selected because the neutral globe temperature was 19.1°C in daytime (the indoor neutral temperature is affected by firewood combustion, thus the figure from semi-open space was used (19.1°C), Rijal et al., 2002, 2003). The difference between these temperatures can be achieved by increasing the clo-value by using blankets during the night, which increases the thermal comfort of the residents. In addition, the globe temperature was also higher than the indoor air temperature. Figure 4 shows the indoor air temperature of the “Base model” and that under “Reduced firewood consumption”.

The indoor air temperature profile of under “Reduced firewood consumption” is similar to that of the “Base model”. $T_{b}$ measurements under “Reduced firewood consumption” were 22.0°C (1F), 19.3°C (2F) and 15.6°C (3F) and the targeted value was achieved as mentioned above. These values were 3.9K (1F), 4.0K (2F) and 1.0K (3F), higher than the “Base model”, despite a 60% reduction in firewood consumption. The indoor air temperatures were 7.0K (1F) and 4.3K (2F), higher than the targeted value. However, elderly people sleep on 1F and 2F, and their neutral temperature is higher (Miura 1968), thus this increase is a desirable improvement. The maximum indoor air temperature on 3F was 1K lower than the “Base model” in daytime, however, residents rarely use this space, thus there is no problem. The reduction in firewood consumption observed in the present research (60%) was similar to the research in which firewood consumption was reduced by 20 to 50%, using an improved cooking stove to replace the open-hearth (CRT, 2002 and RECAST, AEPC, 2002).

ACH under “Reduced firewood consumption” was 1 to 2 times lower than with the “Integrated improved” for each floor. Improved ventilation was caused by the temperature difference due to the reduction in firewood combustion. ACH decreased by 66% during firewood combustion, which was close to the reduction in firewood consumption (60%). The indoor air pollution level shows a corresponding decrease. Finally, the amount of ventilation was also higher than 1.6 ACH at night (over 3 times that of the well-insulated, airtight house). Without firewood consumption at night, there is sufficient ventilation for sleeping.

CONCLUSIONS

To predict and improve the thermal environment during the winter, thermal simulation was conducted for a traditional house before and after improvements and the following findings were obtained.

1) The predicted mean indoor air temperature was – 0.3 to 1.3K higher than the measured value. The Root Mean Square Error was 1.0 to 1.8K. The results show that the indoor air temperature is well predicted by the simulation model.

2) The nighttime indoor air temperature of the “Integrated improved” house model was 4.4 to 12.7K higher than the “Base model”. When firewood consumption was reduced by 60% under the “Integrated improved” model, the nighttime indoor air temperature was 1.0 to 4.0K higher than under the “Base model”. This indicates that closing windows, doors, etc., to make the building airtight, and insulation of the roof using local building material and technology are highly effective for thermal improvement and saving firewood.

Note

Note 1: In winter, symptoms of colds, such as running noses and coughs are often seen in children and elderly people. The incidence of death,
especially in the aged, is high in winter. Moreover, residents wake up frequently because of the cold, and once awake, find it difficult to return to sleep. It can be said that low air temperature at night has a negative effect on health.

Note 2: In the thermal comfort survey, residents were reporting "comfortable" in daytime during the winter. However, there has not been an investigation for nighttime. The measured mean indoor air temperature was 16.6°C (1F), 15.6°C (2F), and 12.5°C (3F) at night during winter, especially on 3F, where the air temperature was very low. The elderly sleep on 1F to 2F, making it necessary to increase the indoor air temperature.

Note 3: The architectural, environmental, and engineering improvements were first proposed and selected after discussion with local people, and were finally implemented in January 2003. To the extent possible, locally-available, natural building materials and carpentry techniques were used for the improvement of the existing house. This approach is effective in sustaining the local lifestyle and retaining beauty without destroying the original house form, and to develop traditional housing building technology. The improved house is popular among the villagers, and this approach to improvement can be implemented widely.

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REFERENCES


Centre for Rural Technology (CRT), Improved Stove Is Beautiful and Good for Health, (without published date, approx. 2003, in Nepalese)


