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Residential Building Walls and Environment in Amman, Jordan

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Abstract

Jordan has a moderate weather conditions which is overwhelmingly dry. Winter months, December, January and February usually have cold spells with rain, wind and occasional snow. Residential buildings are well built with an outer white stone layer on walls and relatively well sealed windows. Most houses are fitted with central heating systems and water heating using Diesel fuel fired boilers. The high cost of fuel renders limited and intermittent use of the space heating system or as an alternative, the use of flu-less paraffin and gas fired heaters. This in addition to cooking and other occupant activities cause the inside environment to become unhealthy and uncomfortable in winter when ventilation is kept to its minimum. Dampness often leads to mold growth on cold surfaces of walls and ceiling.

The present study is experimental with some theoretical analysis of walls thermal properties in an attempt to reach some solutions.

The results indicates that insulation of walls plus some means of ventilation with heat recovery can actually save energy, improve inside air quality and avoid moisture.

Keywords: *Building walls; Air quality; Insulation; Energy; Moisture; Ventilation.*

1. Introduction

The inside environment in residential buildings is controlled mainly by outside conditions, the heating method, walls thermal insulation specifications and ventilation, (ASHRAE hand book of fundamentals, 2001).

Amman is at location with latitude 32^{o}N, enjoys a moderate weather conditions, winter average low temperature of 8^{o}C and summer average high temperature of 30^{o}C, (Outside design conditions for winter is 2^{o}C and for summer 33^{o}C). The ambient temperatures seldom drop below freezing point, once in five to six years and rarely rise above 35^{o}C. The annual rain fall averages at about 270 mm, (Jordan weather record and averages, http://weather.yahoo.com).

In contrast to these moderate weather conditions and the short winter season, the heating process in most residential buildings falls short of comfort conditions as result of high energy cost. A cold season seldom pass without reported accidents as result of lack of oxygen or high CO_2 & CO concentration caused by use of flue less heaters in small rooms or baths behind locked doors. Moisture traces is often seen on walls inside buildings.

The majority of residential buildings in Amman have oil fired central heating systems. Yet for economic reasons flue-less gas and paraffin heaters are often used, for the same reason many apartments today have instant-gas-water-heaters installed. These heaters are always fixed inside without exhaust ducts to outside.

The builders in Amman fit good air tight windows but do not have the habit to provide a place for fitting extraction fans in the kitchens. Found in some kitchens, is a small 10-15cm diameter fan usually fixed on the window glass at a moderate height.

Ventilation essential in the cases indicated above usually increase the heating load. The latter can be reduced to its minimum by using heat recovery ventilators and walls with proper insulation. These precautions will improve inside conditions to comfort temperatures and cause less moisture with reduced energy cost.

2. Analysis and Measurements

Three different apartments North-West of Amman are taken into consideration. It has been observed that during the cold season, a high fuel cost is needed to keep the inside conditions near comfort. The rooms with external walls facing north, east and west remained damp and

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uncomfortable. The inner surface of these walls showed traces of moisture and moulds by end of the season that often requires cleaning or painting. These observations encouraged this investigation to possible causes and solutions for the problem.
It is well known that mould growth on the interior walls of buildings is associated with condensation or high relative humidity adjacent to the inner cold walls surfaces when its temperature drops below or comes close to the dew point temperature, (Straube, 2002 and McMullan, 2002).
Measurements of temperature and relative humidity of ambient air, interior air and walls surface temperature for several apartments are taken during the cold seasons.
A simple steady-state heat transfer analysis for typical walls of buildings in Amman region is used to predict walls thermal specification and surface temperatures.
Assuming composite multi-layer walls, then the overall heat transfer may be expressed as:

$$q^o = \frac{Q^o}{A} = \frac{[T_i - T_o]}{\{\frac{1}{h_i} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} + \frac{1}{h_o}\}} = U[T_i - T_o] \quad (1)$$

And/ or

$$q^o = \frac{[T_i - T_1]}{\frac{1}{h_i}} = \frac{[T_1 - T_2]}{\frac{x_1}{k_1}} = \frac{[T_2 - T_3]}{\frac{x_2}{k_2}} = \frac{[T_3 - T_4]}{\frac{x_3}{k_3}} = \frac{[T_4 - T_o]}{\frac{1}{h_o}} \quad (2)$$

Where,
q^o is the heat transfer rate (W/m^2)
T_i & T_o are the inside and outside air temperatures (^{o}C)
h_i & h_o are the inside and outside film heat transfer coefficients (W/m^2 K)
Typical values taken for winter are h_i=8.3 and h_o=33.3 W/m^2 K.
k_1, k_2 ,*etc* are thermal conductivity of different layers of wall material (W/m K)
x_1, x_2,*etc* are the different wall layers thickness (m)
U is the wall overall heat transfer coefficient (W/m^2 K)
Then for a wall with defined specifications, known inside and outside temperatures, the wall layers and inside surface temperature can be predicted.
Inspection of several buildings under construction showed that external walls consisted of: inner hollow-brick layer with plaster, outer enclosure layer of white stone and a cement filling layer in between. In rare cases an insulation layer is added.
The types of the walls found most common and considered for analysis were of dimensions and specifications given in Table 1. Included are the calculated properties, as *U*-value and the thermal time-lag of the walls.

The analysis considering these walls can give an estimate of the heat loads and an indication of temperatures expected in different buildings under different ambient conditions, (Sauer et al., 2001). The predicted results are compared with the measured data in actual buildings.

Actual field data were collected during the cold seasons from three different apartments. The three apartments are located in a North-West suburb and one of the cold regions of Amman city in winter. See appendix A.
A hygrometer (dry & wet bulb thermometer type) was used for the relative humidity and a digital potentiometer using K-type surface thermocouple for measurement of wall surface temperatures.

3. Results and Discussion

The cold season in Amman starts in December and ends in March. The measured data were collected when the ambient temperature dropped to about five degree Centigrade and below.
The daily variation of ambient temperature, the inside room air temperature, room air relative humidity, the wall inside surface temperature and the evaluated due-point temperature for the apartment No.1 are shown in Figure 1. Note that for any ambient RH (say 90%), adding the necessary heating to air in cold season will dry the air to say 40%. However, the air regains higher RH (50%-70%) by functions such as cooking, respiration and flue-less gas or paraffin heaters, (Straube, 2002, Sauer et al 2001).
It is interesting to see occasional drop of wall inside surface temperature close to or below dew-point temperature, this indicates condensation on the walls surface. This phenomenon is likely to happen more near the ceiling where the air temperature is slightly higher than measured values at head level. Traces of moulds growth are usually seen at the ceiling edge extending down on walls and at window edges, also behind drawers and curtains encouraged by still air, see images below.
Figure 2 show sample daily history of measured RH in different spaces of an apartment. The values ranging between 55% and 75% are affected by different factors such as heating, respiration, cooking, condensation on windows and ventilation. These values of RH in buildings together with room air temperatures of 18 to 20^{o}C will have dew point temperatures between 10^{o}C to 15^{o}C. Then condensation will occur on walls with inside surface temperatures less than 15^{o}C. Some observed inside surface temperatures in the apartments were as low as 11^{o}C at ambient conditions of 5^{o}C or below. No traces of molds or moisture are observed on unexposed walls surfaces at 15^{o}C or greater.
Heat analysis of typical walls, A, B, C and D used in buildings in Amman give heat transfer coefficients (U) and time lag values as shown in Table 1. The results show that heat transfer for wall A can be reduced to half when a 2cm thick insulation is added (wall C). This will allow for some ventilation.
Then the estimated time lag for walls in range of 6 hours indicates possible coincidence of minimum inside surface temperatures with high inside RH due to cooking at noon and possible condensation.

The estimated temperatures across the walls A, B, C and D are shown in Figures 3a, 3b, 3c and 3d respectively. Figure 3a for the heavy type wall (A) show that inside wall surface temperatures can drop below 15^{o}C only when room air at 18^{o}C or less with the ambient conditions of 5^{o}C or less. Thus condensation may take place at the inner surface of this wall at ambient conditions of Zero Centigrade and below.

Figure 3b show the temperature curves for the lighter wall B, note the inside wall surface temperatures are below the values in wall A. Traces of moisture is often seen in commercial buildings with this type of walls.

The wall C is the same as the wall A, but with 2cm of insulation added. The heat transfer coefficient of this wall is reduced to more than half the value for wall A as shown in Table 1, and the inside surface temperature remain above 15^{o}C. Figure 3c show the estimated temperature distribution for wall C at ambient temperatures below zero and down to -5^{o}C. A sample of measured temperature across wall is also shown. Condensation on this wall is less likely and actually no traces of moisture appeared as it was before adding the insulation.

Concrete walls on the other hand results lower inside surface temperatures as seen in Figure 3d. This supports the moisture traces and moulds growth appearing near the ceiling and bridges.

In general no trace of moisture has been observed on wall surfaces at 15^{o}C or above as the case with internal section walls or walls exposed to outside but have insulation. Assuming the outside ambient conditions at Zero temperature and room temperature at 20^{o}C, It may be possible to conclude that the condition for no-condensation is approximately when, $(T_{iw} - T_o)/ (T_i - T_o) \geq 0.75$, may call "Condensation factor". Where T_{iw} is the wall inside surface temperature ($T_{iw}= T_1$ in equations 1 and 2), Sulaiman and Badran, 2010.

The observed room air temperatures and wall inside surface temperature for several occupied apartments, used to predict the room air relative humidity and the dew point temperature are shown in Figure 4. It can be seen that under certain conditions, the inside wall surface temperature actually drops below the dew point temperature. Therefore condensation actually takes place on walls at these conditions but is not as visible as the case with condensation on windows.

These observations indicate that the room air temperatures recorded are in general lower than comfort values, which reflects the high energy cost that most people find unbearable. The calculated mean value of room air temperature is 17.8^{o}C and the mean value of the room air RH is found to be 60%. The condition for these mean values falls on the left and actually short of the standard winter comfort zone, (20^{o}C- 24^{o}C and RH= 30%- 75%). These relatively low inside temperatures with occasional condensation lead to unhealthy damp conditions which require some precautions. Walls insulation and good ventilation with heat recovery can improve indoor air quality as shown by Awbi, 1986.

For comparison, the heating in apartment No. 1 was partially by central heating and partially by the use of kerosene heaters, the exposed walls showed traces of moisture. A similar apartment in the same building used only central heating with no hesitation. The seasonal consumption was 1800 liter of fuel, three times as consumed by apartment No. 1. The seasonal difference in cost of fuel was about 500JD ($700). No traces appeared in the neighboring apartment and comfort achieved through the cold season. The penalty of unaffordable energy cost is lack of comfort and seasonal problems of cleaning wall traces or repainting the walls.

4. Conclusions

High energy cost in Jordan and poor building walls thermal specifications are the two major factors that cause the inside living environment during the cold season to fall short off comfort conditions, damp and unhealthy.

In most cases the attempt is to keep the heat inside with no ventilation (infiltration only), this further increase dampness and lead to less comfort and appearance of moisture traces on walls.

The present study show that the inside air quality can be improved by insulation of walls and the use of some heat-recovery system for ventilation. The heat recovery systems are simple and can be cheap if widely used. These modifications will save energy, provide comfort and prevent the appearance of moisture traces.

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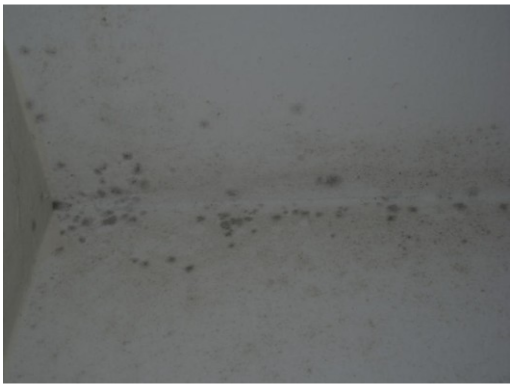
Table 1. Specification of typical walls considered, layers thickness and properties.

Layer / Wall Type	Hollow Brick (m)	Cement Filling (m)	Insulation (m)	White Stone (m)	Total Wall (m)	U-value (W/m^2K)	Thermal Lag (h)
Common (A)	0.1	0.15	None	0.07	0.32	2.5	6.0
Economy (B)	0.1	0.1	None	0.07	0.27	2.8	5.8
Insulated (C)	0.1	0.15	0.02	0.07	0.34	0.94	6.2
Concrete (D)	None	0.25	None	0.07	0.32	2.9	6
Thermal-Conductivity (W/m K)	1.1 Ref.(7)	1.2 Ref.(7)	0.03 Ref.(7)	2.0 Measured			

Ceiling



Walls and Ceiling

Next to Drawer

Fig. 1. Images of some samples of moisture traces and molds growth on ceiling and walls of residential buildings

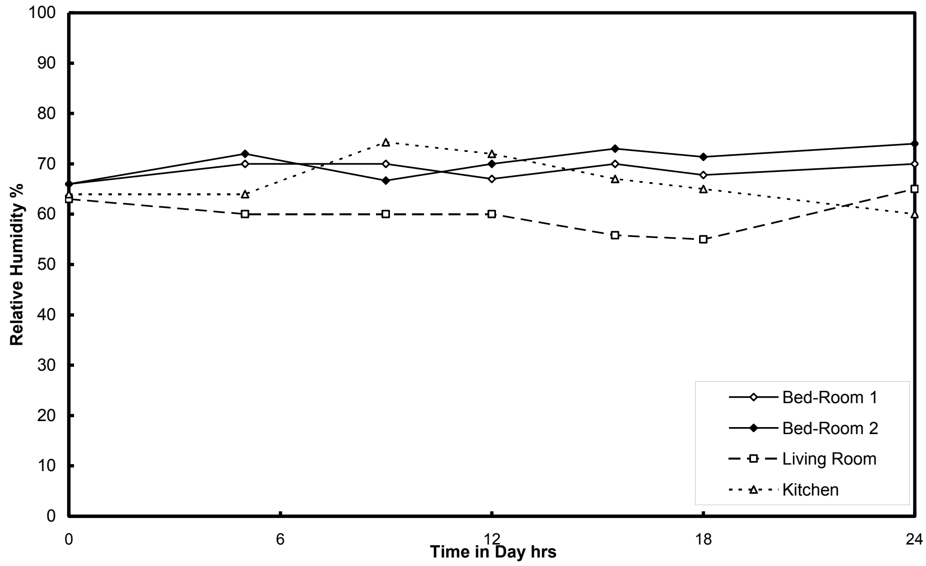


Figure 2. Daily Relative Humidity Variation for Different Spaces in Apartment 2 (Ambient, RH=80%, T=6°C)

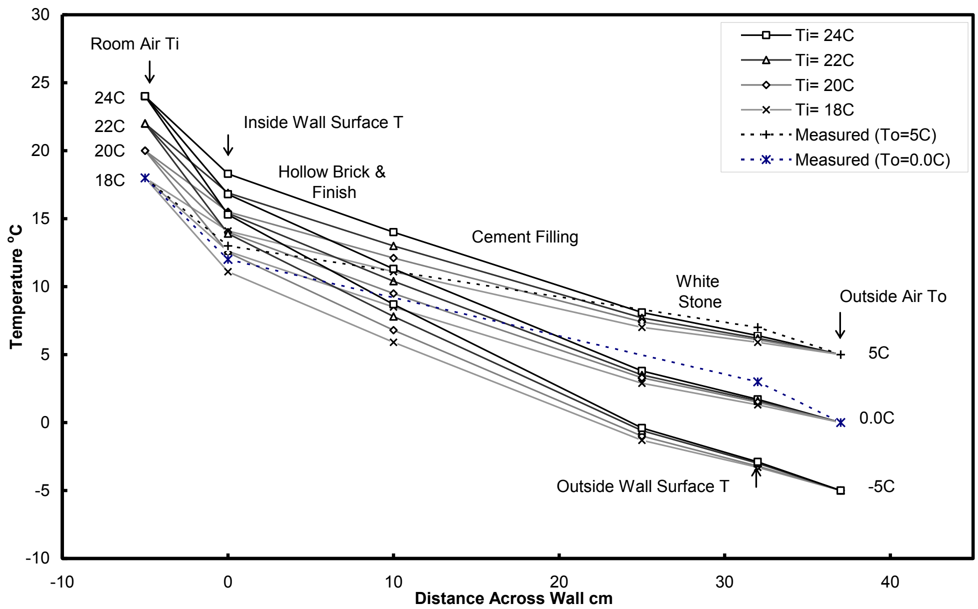


Figure 3a. Estimated Temperature Distribution in Wall (A) at Different Outside and Inside Temperatures and Two Measured Samples

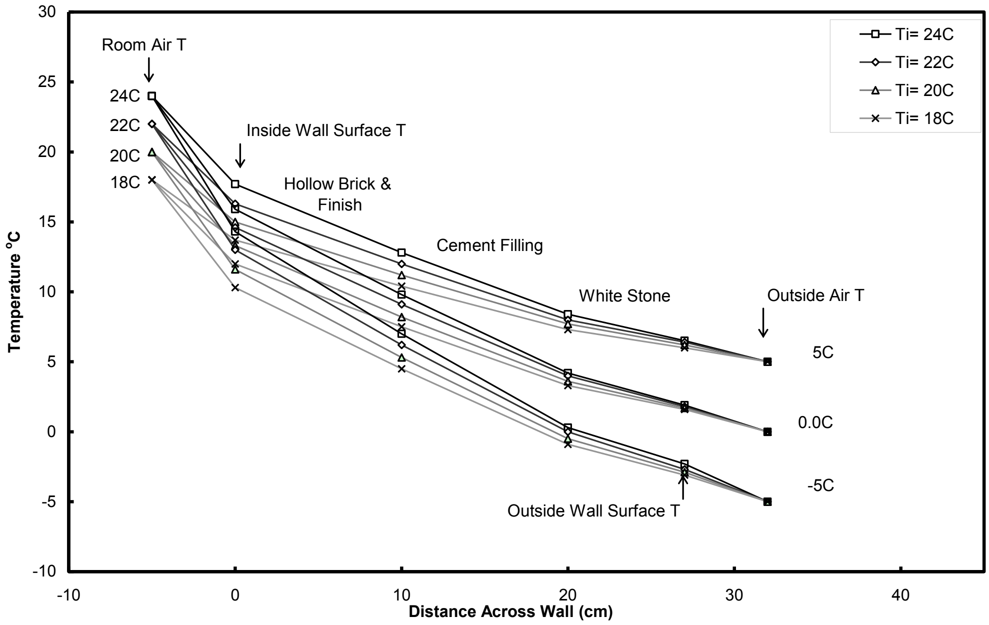


Figure 3b. Estimated Temperature Distribution in Wall (B) at Different Outside and Inside Temperatures

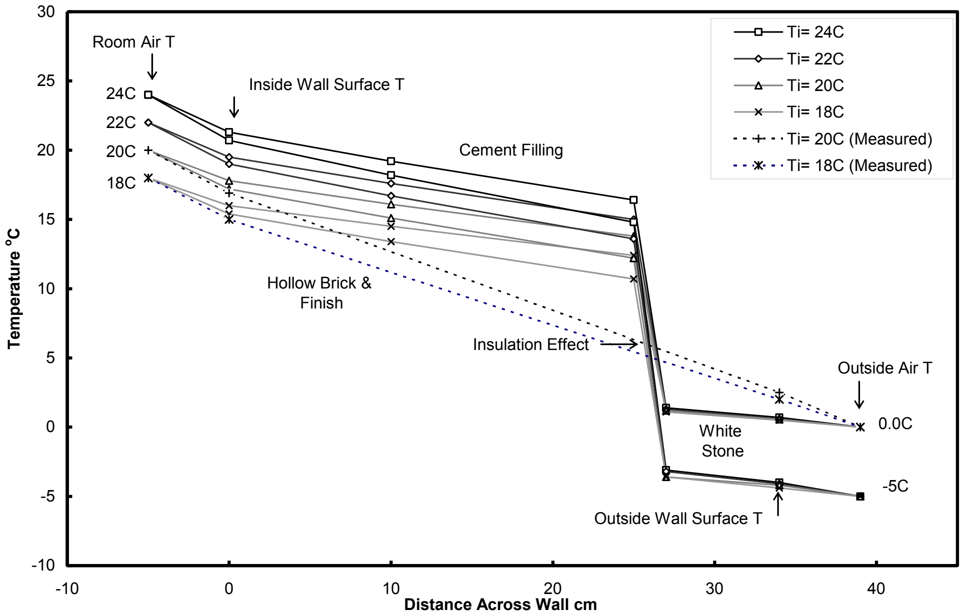


Figure 3c. Estimated Temperature Distribution in Wall (C) at Different Outside and Inside Temperatures and Two Measured Samples

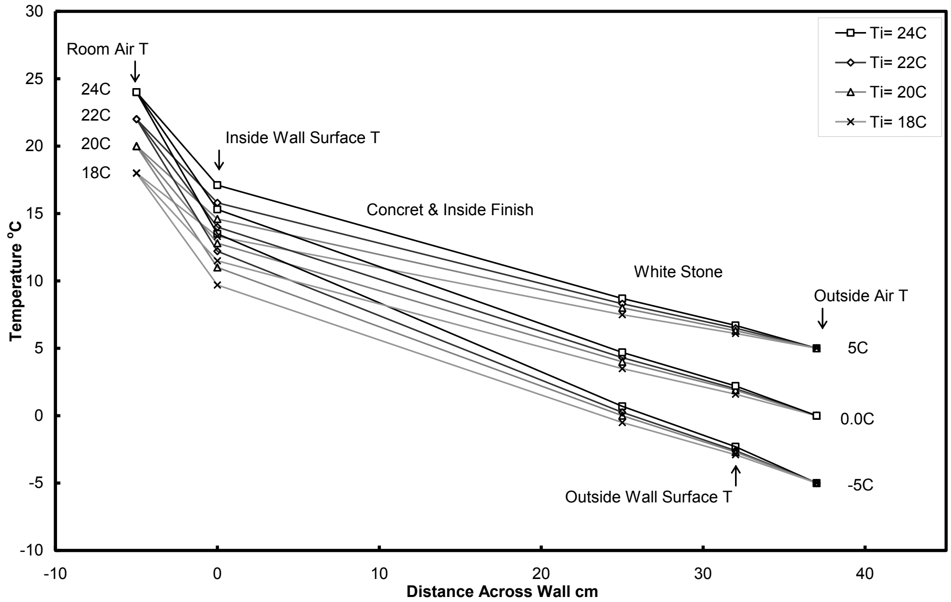


Figure 3d. Estimated Temperature Distribution in a Solid Concerete Wall (D) at Different Outside and Inside Temperatures

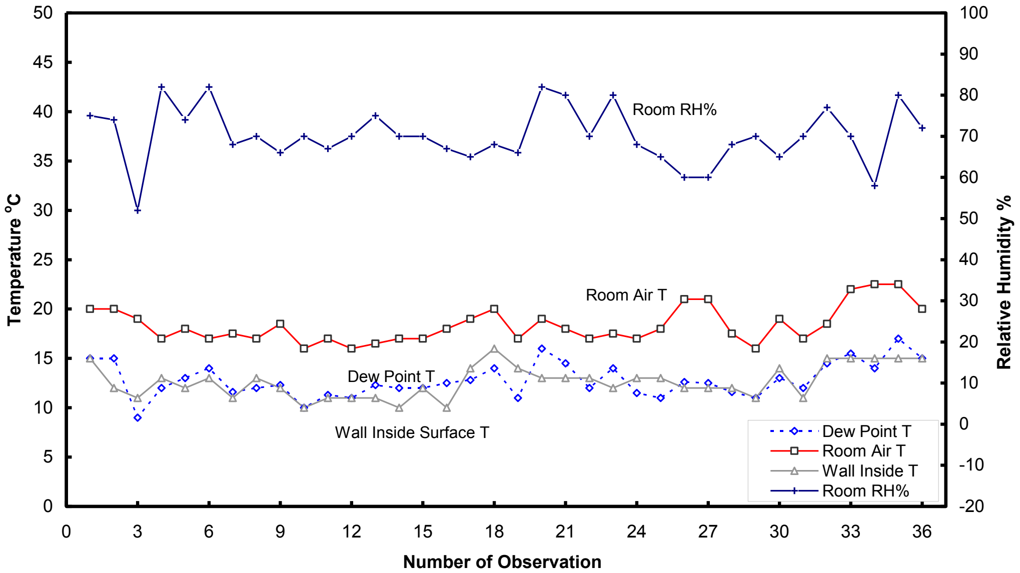


Figure 4. Measured Room Air and Wall Inside Surface Temperatures, Room RH and the Dew-Point Temperature in Different Apartments