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미국의 중심부인 텍사스주에 위치하는 Habitat For Humanity House(평화주택)의 실내쾌적조건에 관한 연구

Indoor Comfort Conditions In A Habitat For Humanity House In Central Texas

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<요 약>

이 논문은 미국의 중심부인 텍사스주에 위치하는 평화 주택의 실내외 환경을 측정하여 쾌적한 조건을 분석한 기초자료이다. 이 사례연구는 주택의 실내외온도, 습도, 그리고 이산화탄소농도를 측정하여 쾌적한 조건을 만드는 범위에 대하여 검토하였다. 바닥온도 3가지는 겨울철 차가운 바닥의 영향에 대하여서도 검토를 하였다. 이 논문은 또한 부가적인 비용의 증가 없이 평화 주택이 보다 쾌적한 실내환경을 계획할 때 이용할 수 있는 자료로 활용하는데 연구의 목적이 있다.

Key Words : Habitat for Humanity House, CO_2 levels, Comfort Conditions, Indoor-Outdoor Temperature, Humidity

INTRODUCTION

Habitat for Humanity is an international, volunteer, religious organization that has been established to development affordable, low cost housing. Habitat homes are low cost, high quality, energy efficient houses constructed with volunteer labor and materials that utilize no or low interest loans to keep monthly payments low. Qualified Habitat homeowners are required to participate in the construction of their homes. Their 'sweat equity' also keeps the cost of the homes low. Habitat for Humanity provides services to homeowners from local offices located in all 50 of the United States and in 51 countries around the world[1].

The design of each Habitat home varies with location with the overall goal of providing a low cost, energy efficient, durable home. Several efforts have been performed to evaluate the effectiveness of the energy efficiency features in selected Habitat homes in hot and humid locations including effects in Texas[2)3)] and Florida[4)5)6)].

These reports have shown that efficient equipment selection, selected envelope measures (i.e., white roofs), and overall construction quality

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이 논문은 1998년도 제주대학교 발전기금 국외파견연구지원 계획에 의하여 연구되었다.

as effective energy conserving measures for Habitat houses located in hot and humid climates. However, all the previous efforts have assumed that the indoor environments in the Habitat houses are comfortable and healthy and / or performed a limited analysis of the indoor conditions. This paper reports on efforts to investigate the indoor environment of a monitored Habitat for Humanity Houses in central Texas.

METHODOLOGY

Background

The Habitat for Humanity Houses in this study is a single-story 1048ft^2(97.4㎡), three-bedroom house with an attic space located in Bryan, Texas. Measured data are recorded with an on-site data logger that was installed during the construction period in 1997. The house has a kitchen/dining area, utility room and two bathrooms. The house has a 64 ft^2(6㎡) front porch with a 42 ft^2(4 ㎡) patio at the rear of the house.

Table 1. Energy and Environmental Channels Recorded by the Data Logger. This table contains the channel descriptions from the data logger installed at the case study house. The channel types include power monitoring(KW), analog channel(AN), and digital channels(DIG).

Description	Channel	Description	Channel
WHL HSE ELE L1	KW0	RH-RETURN	AN5
WHL HSE ELE L2	KW1	TEM-RETURN	AN6
DRYER	KW2	CO_2-INDOOR	AN7
A/C	KW3	CO_2-OUTDOOR	AN8
A/C BLOWER	KW4	SOLAR RADIATION	AN9
REFRIGERATOR	KW5	WIND SPEED	AN10
FREEZER	KW6	RH-OUTDOOR	AN11
CLOTHES WASHER	KW7	TEM-OUTDOOR	AN12
DISHWASHER	KW8	RH-ATTIC	AN13
		TEM-ATTIC	AN14
GND TEM-NORTH	AN0		
GND TEM-CENTER	AN1	FLOW MTER	DIG0
GND TEM-SOUTH	AN2	BTU METER	DIG1
RH SUPPLY	AN3	NATURAL GAS L-1	DIG2
TEMP-SUPPLY	AN4		

The house is constructed with 4 inch(102 ㎜) concrete slab on grade with grade beams at 10 foot(305㎜) centers laid over an impermeable vapor barrier. The exterior 2×4 stud walls[16 inch(406㎜) O.C.] are composed of ½ inch(27㎜) gypsum, R-13 blown-in cellulose insulation, ½ inch(27㎜) foil-faced foamboard insulation, Tyvek water barrier, and vinyl siding. The ceiling is ½ inch(27㎜) gypsum on 2×6 inch(51×152㎜) ceiling joists[24 inch(610㎜) O.C.] and R19 blown-in fiberglass insulation. The roof construction consists of composite shingles on felt underlayment, with a 5/8 inch(16㎜) plywood deck supported by 2×6 inch(51×152㎜) trusses [24 inch(610㎜) O.C.] and has an 18 inch(457㎜) overhang. The house' s heating and cooling systems consists of a central, forced air, heating and cooling system, with a natural gas furnace and air conditioner.

A 50 channel data logger was installed during the construction of the house to record 15-minute energy and environmental conditions. Electrical monitoring includes the whole-house electricity, and sub-metering for the clothes dryer, air-conditioner, air-conditioner blower, refrigerator, freezer, clothes washer and dishwasher. Additional thermal metering includes the whole-building natural gas and thermal metering of the domestic water heater. Environmental metering includes three ground temperatures beneath the house, indoor temperature, humidity and CO_2, attic temperature and humidity, HVAC supply air temperature and humidity, and ambient temperature, humidity, CO_2, horizontal solar and wind speed as indicated in Table 1. All sensors were calibrated against NIST-traceable instruments at the Energy Systems Laboratory (ESL)[7]. Data from the data logger are downloaded weekly, inspected for errors and loaded into the ELS' s relational database.

RESULTS

Temperature measurements

Preliminary results of the monitoring efforts are included in Fig. 1 to 7. Fig.1 shows measured 15-minute temperatures from the attic, ambient, and indoor air sensor, along with ground temperatures located below the slab in the center of the house[C], and 3 feet(914㎜) from the edge the slab on the [N] and south [S] sides for a three week period in January-February 1999. It is clear this figure that the ceiling and walls of the house are exposed to significant variations in diurnal exterior temperatures with ambient wall temperatures varying from 30 F (−1.1℃) to 80 F(26.7℃) and attic temperatures varying from the 30 F(−1.1℃) to over 100 F(37.8℃). The attic temperatures rise significantly above the ambient temperatures during the daytime, as the solar heat gain penetrates the surface of the roof. However, the attic temperatures almost always drop to the same temperature as the ambient temperatures each evening-an effect of the vented attic.

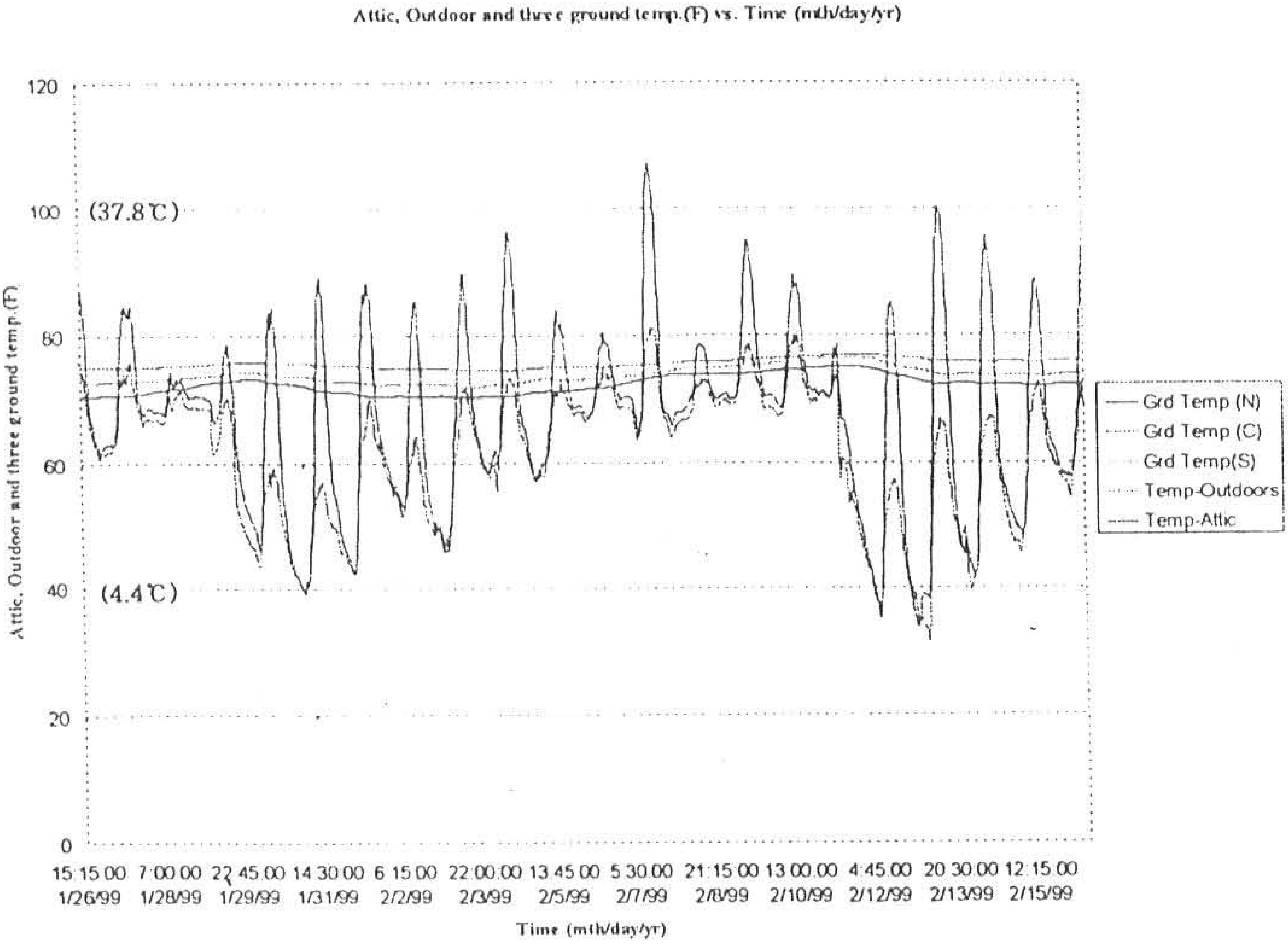

Fig.1 15-minute Environmental Temperatures Measured at the Case Study House. This figure shows measured 15-minute temperatures from the attic, ambient, and indoor air sensors, also with ground temperatures located below the slab in the center of the house[C], and 3 feet(914㎜) from the edge of the slab on the [N] and south [S] sides.

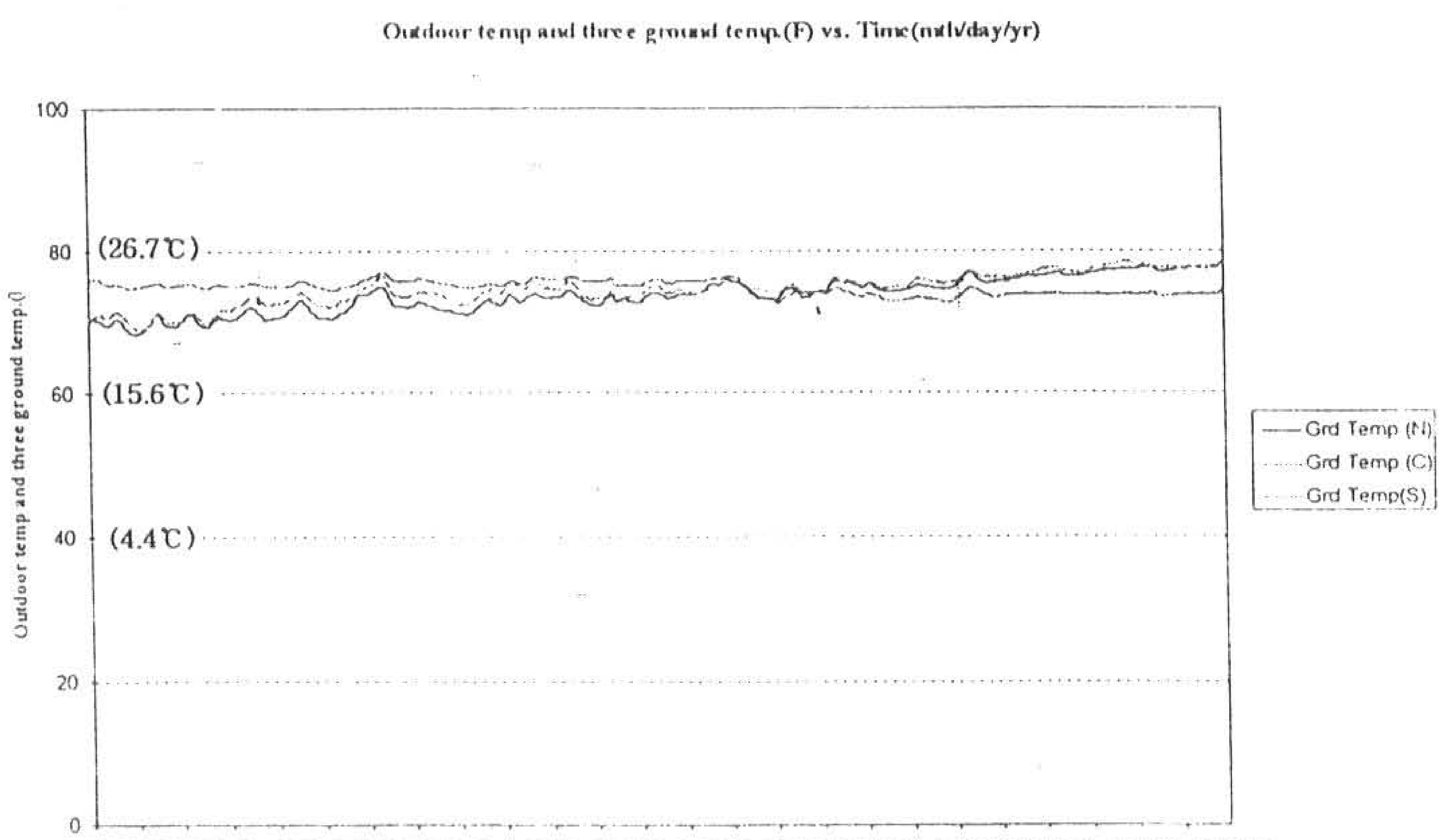

Fig.2 : Daily Ground Temperatures Measured at the Case Study House. This figure shows measured ground temperatures located below the slab in the center of the house[C], and 3 feet (914㎜) from the edge of the slab on the [N] and south [S] sides for a 6 month period from December 1998 to June 1999.

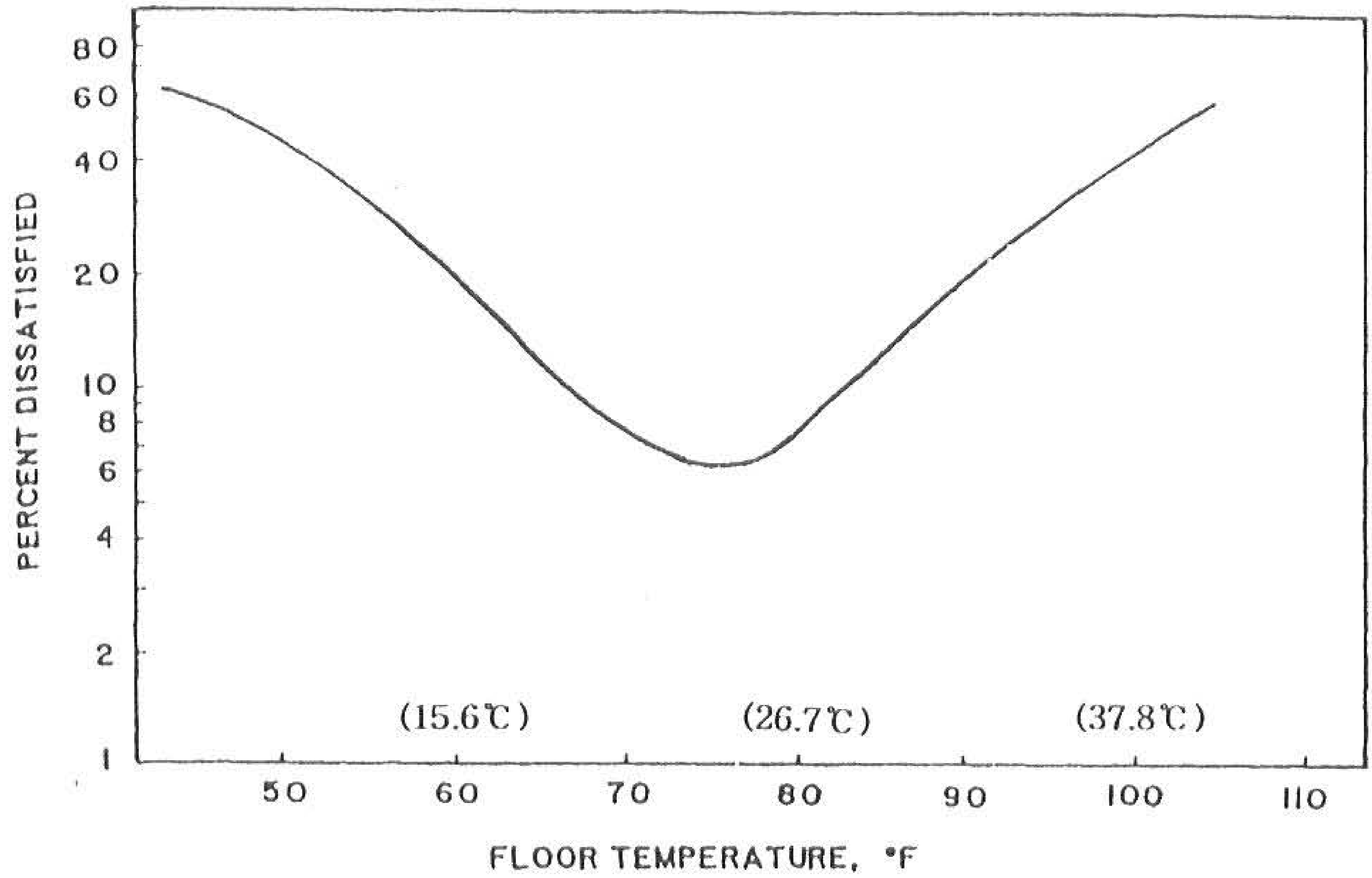

Fig.3 ASHRAE Recommended Slab Temperatures for Bare Feet. This figure shows the 77 F(25℃) ASHRAE recommended slab temperature for bare feet on a concrete slab(ASHRAE 1997).

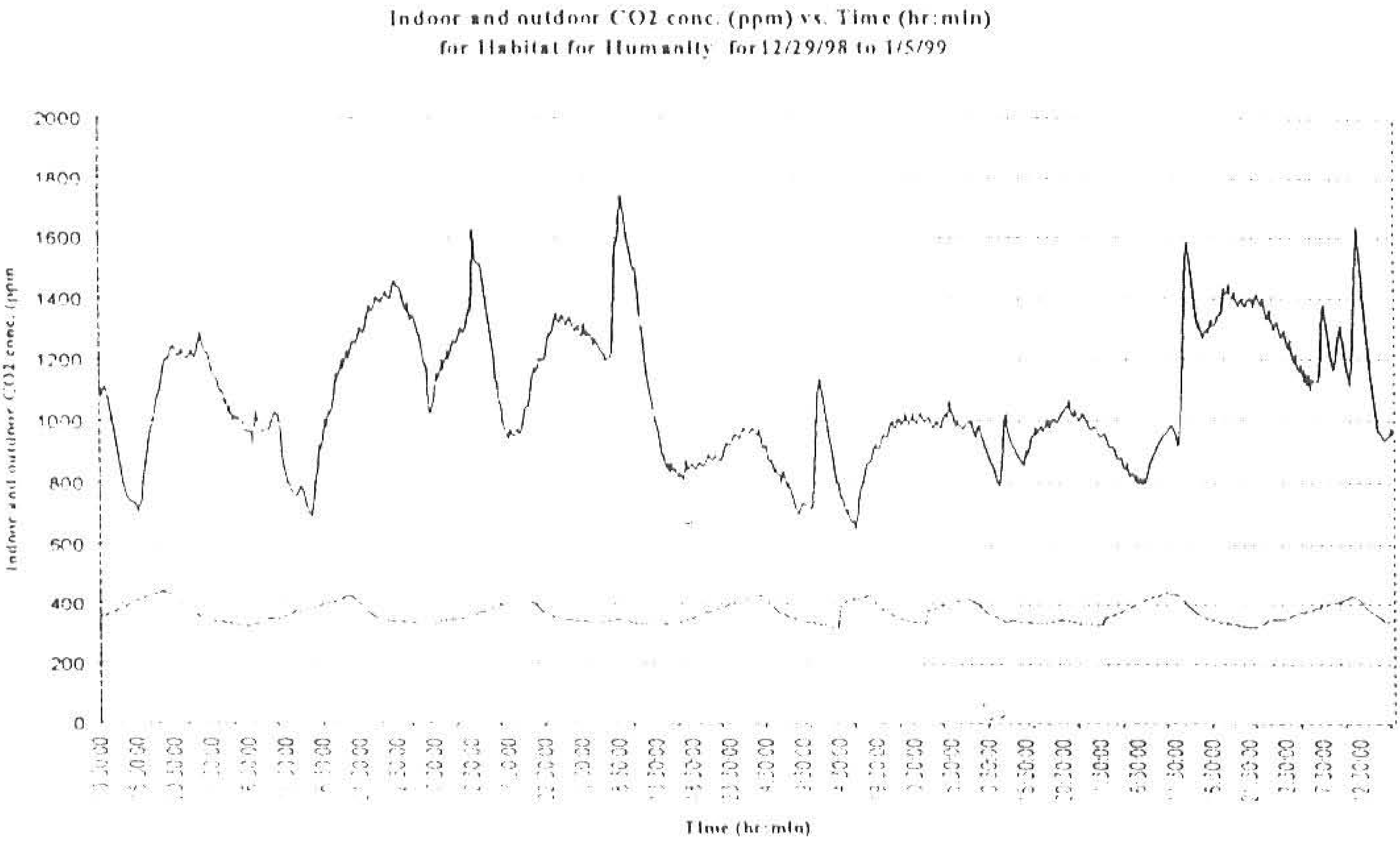

Fig.4 15-minute Measured Indoor and Outdoor CO_2 Concentrations. This figure shows one week of measured 15-minute indoor-outdoor CO_2 concentrations from the case study house for the period 12/28/98 to 1/5/99.

During this same period the measured ground temperatures directly below the concrete slab varied little with the center of the slab remaining the closest to the indoor air temperature. The temperatures near the edges of the slab are slightly lower than the central slab temperature indicating the uninsulated edges of the concrete slab are allowing the exterior cold temperatures to penetrate into the interior of the house.

Fig.2 shows measured ground temperatures located below the slab in the center of the house[C], and 3 feet(914㎜) from the edge of the slab on the [N] and south [S] sides for a 6-month period from December 1998 to June 1999. These measured temperatures clearly show that there are significant periods in the winter when the edges of the concrete slab are well below the 77 F(25℃) recommended by ASHRAE for bare feet in contact with an uncarpeted floor(Fig.3).

Several other features are evident as well from Fig.1 and Fig. 2. First, in Fig.1 during the three week period that is shown there was a warming period in the middle of February followed by 40+F(4.4+℃) drop in temperature on February 11th. During the warming period the slab temperatures converged towards the room temperature. Whereas, one day following the outdoor temperature drop the temperatures at the edges of the slab started to drop away from the center slab temperature. Second, in Fig. 2 the temperature of the center of the slab remains relatively constant throughout the 6-month period due to the direct contract with the conditioned air in the building. Finally, the edges of the slab vary from about 60F(15.6℃) in the middle of the winter to almost 80F(26.7℃) by the summer, indicating a significant influence from the outdoor temperature.

CO_2 measurements.

Fig.4 and 5 show measured indoor-outdoor CO_2 concentrations. Fig. 4 shows 15-minute measured indoor and outdoor CO_2 concentrations for one week for the period 12/28/98 to 1/5/99. Clearly, there are significant periods when the house is well above the 1,000 ppm recommended by ASHRAE. Fig. 5 shows 15-minute measured indoor and outdoor CO_2 concentrations for the 2-1/2 month period from 5/13/98 to 7/31/98. During this period there is a period of 10 days when the indoor CO_2 concentration never falls below 1,000 ppm and isolated spikes when the CO_2 concentrations topped 2,500 ppm. However, there are also periods when the CO_2 concentrations did not rise above 1,000 and a few days when the indoor CO_2 concentrations matched the outdoor concentrations. Clearly, one can conclude from these data that the CO_2 concentrations are very dependent upon how many people are in the house and whether or not the house has any windows open.

Temperature-humidity measurements.

Indoor temperature-humidity measurements were also recorded to help analyze the thermal comfort of the house as shown in Fig. 6 and Fig.7. In Fig.6 the indoor-outdoor temperature and humidity are displayed on the psychrometric chart for the 3-month period from January 1999 to March 1999. Fig. 7 shown the indoor-outdoor temperature and humidity for the Month of August 1999.

During the heating mode(Fig.6) several features can be seen in the data. First, there are two distinct indoor temperature-humidity groups : one group where the heating system was clearly operating and the resultant temperature-humidity condition stayed within the confined of the ASHRAE comfort chart for heating(i.e., 60% RH, 68~75 F(20~23.9℃ and 36 Twb). The second mode is a group of indoor temperature-humidity data that fall outside the comfort zone and represent either a periods when ambient temperatures were cold but the heating system was not active(i.e., temperatures colder than the comfort zone), or b)periods when the humidity levels are above the 60% RH recommended by ASHRAE for mold and mildew control.

During the cooling season(Fig.7) a dramatically different picture emerges about the indoor comfort conditions. In this period, which represents the month of August 1999, ambient conditions varied from 75F(23.9℃) to 100F(37.8℃) and were always more humid than the ASHRAE comfort zone, forcing the Habitat homeowner to continuously run her air conditioner. This continuous air-conditioning produced a very tight grouping of the indoor temperature-humidity measurements that range from 65 F(18.3℃) to 75 F(23.9℃) and remained almost entirely with a 40% to 50% band.

DISCUSSION

This paper has presented preliminary results of efforts to measure the energy use and environmental conditions of a Habitat for Humanity House in central Texas. In general, these measurements show that the Habitat House is providing year-around comfort conditions for the homeowner. However, a closer look at the data reveals the following features :

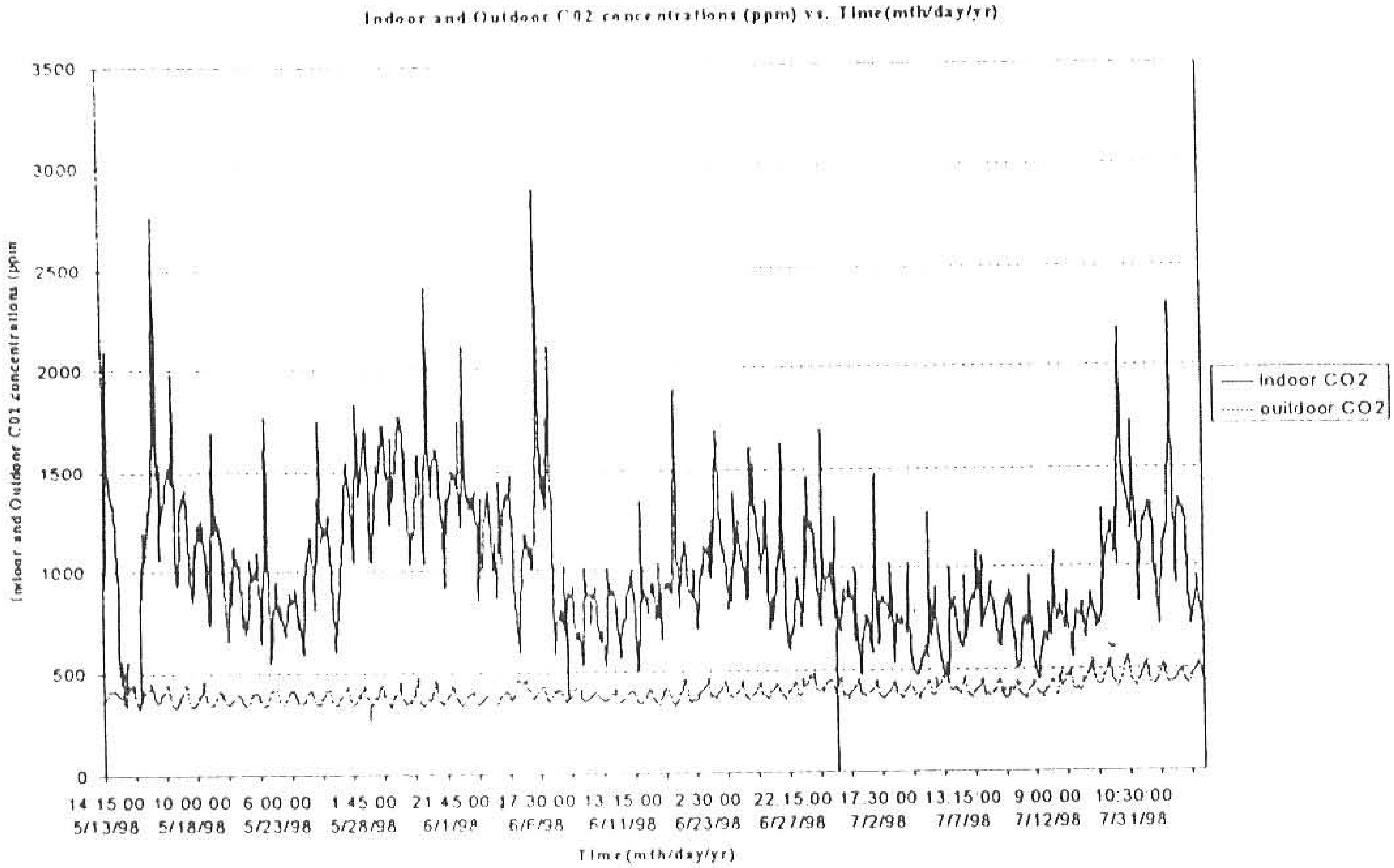

Fig.5 : 15-minute Measured Indoor and Outdoor CO2 Concentrations. This figure shows one week of measured 15-minute indoor-outdoor CO2 concentrations from the case study house for the period 5/13/98 to 7/31/98.

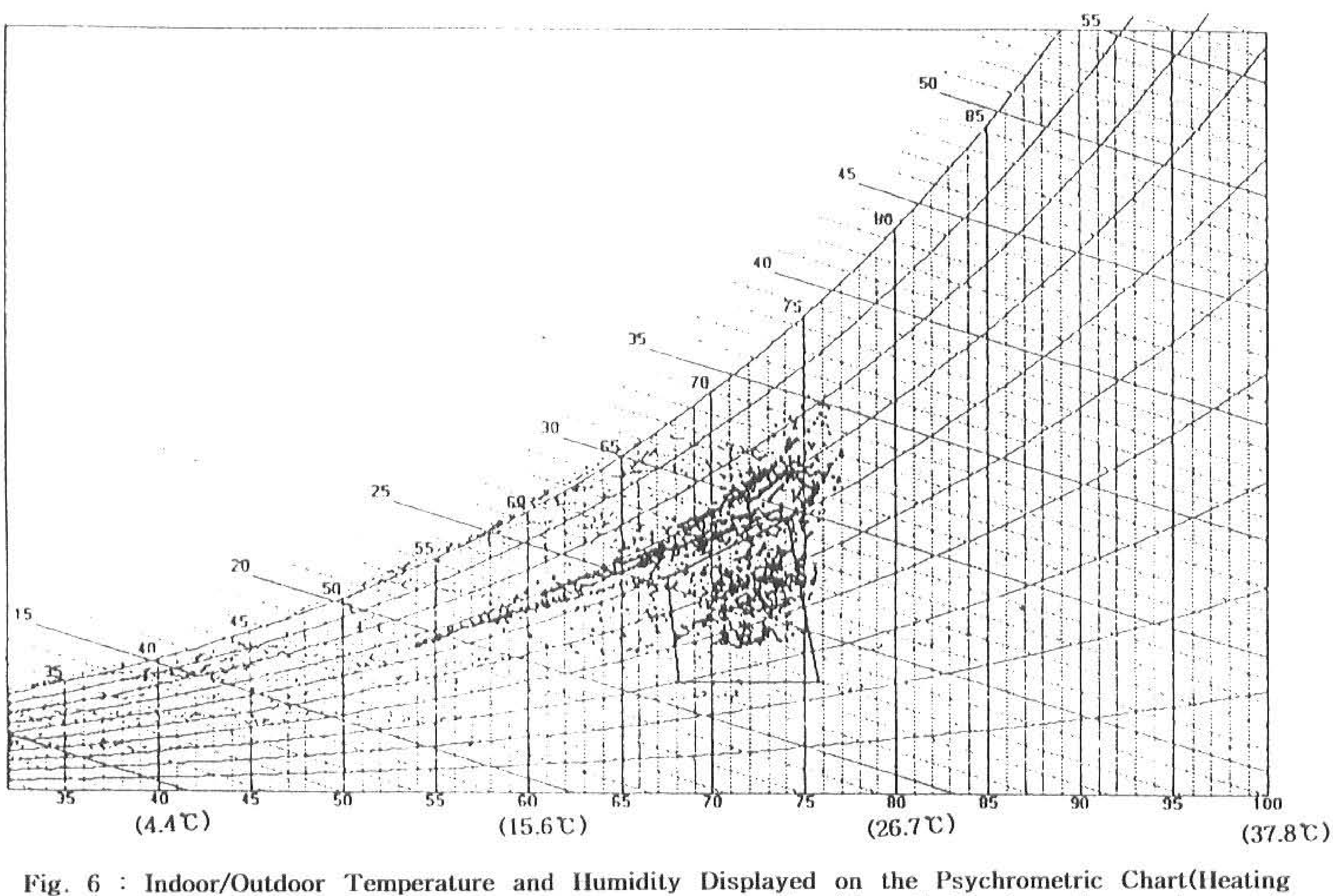

Fig. 6 : Indoor/Outdoor Temperature and Humidity Displayed on the Psychrometric Chart(Heating Mode). This figure shows the measured indoor temperature-humidity displayed on the psychrometric chart during the heating season for the period January to March 1999.

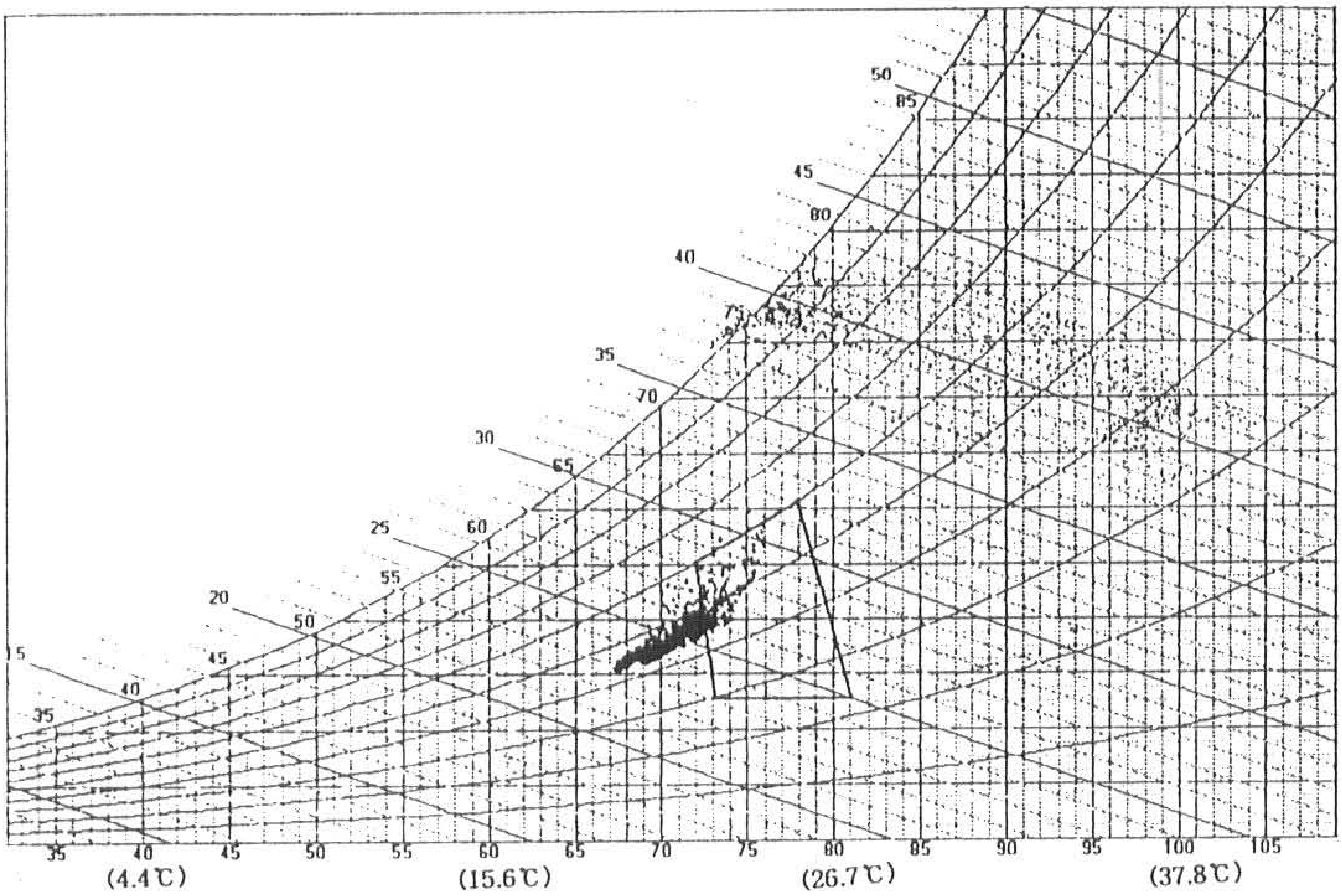

Fig.7 : Indoor/Outdoor Temperature and Humidity Displayed on the Psychrometric Chart(Cooling Mode). This figure shows the measured indoor temperature-humidity displayed on the psychrometric chart during the cooling season for the month of August 1999.

1) The attic temperatures are hot during sunny days in the winter and very hot during sunny days at other periods. Therefore, it is recommended that alternative designs be investigated that will avoid placing air-conditioning equipment and ductwork in the attic where it is exposed to the extreme temperature.

2) Slab temperatures at the edge of the slab are dropping well below the 77 F(25℃) temperature recommended by ASHRAE for bare feet on un-carpeted concrete floors. This may be indicating the need for the perimeter insulation. This recommendation runs counter to ASHRAE Standard 90.1[8] and 90.2[9]. Both of these standards recommend levels of insulation based upon cost effective heat loss mitigation. However, the measurements reported in this paper would indicate that insulation should be recommended based upon comfort conditions.

3) Interior comfort conditions vary during the heating season. The habitat homeowner in the case study house allows the temperatures to drop as low as 55F(12.8℃) during the heating season. High humidity conditions have been observed for the heating season as well. When the heating system is on it does appear to maintain temperatures at or near the ASHRAE recommended conditions[10].

4) Interior comfort conditions are well maintained during the cooling season. Indoor comfort conditions during periods of continuous air-conditioning are well below the 60% RH ASHRAE recommended humidity limit for mold and mildew control. Measurements reveal that the homeowner in the case study house prefers indoor temperatures well below the ASHRAE recommended temperatures.

5) Indoor-outdoor CO_2 measurements indicate higher than expected indoor CO_2 concentrations and may be indicating that the house is too tight and may be in need of a ventilation system. This is also confirmed by blower door measurements that showed 0.3 to 0.5 ACH at 50 Pascals. Indoor CO_2 levels seem to be influenced by door-window opening-closing, use of exhaust fans and number of occupants. CO_2 levels tend to be higher in summer (less infiltration due to stack effect).

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