Supporting Information:

Large-Scale and Long-Term Monitoring of the Thermal Environments and Adaptive Behaviors in Chinese Urban Residential Buildings

S1 Coldest and hottest months

To investigate the interior thermal conditions under extreme exterior circumstances, Figure S1 presents box plots of the indoor and outdoor temperatures of the monitored dwellings in the coldest and hottest months. For the regions with centralized heat supplies, the interior air temperature was in the range of 22 to 26 °C in Urumqi, of 20 to 29 °C in Shenyang, of 20 to 24 °C in Tianjin and of 15 to 25 °C in Xi'an. According to the design code for heating, ventilation and air conditioning of civil buildings [44], in terms of energy conservation and thermal comfort, the setting temperature during the heating season should be in the range of 18 to 24 °C (-1≤PMV≤0). The inside environment was overheated in Urumqi and Shenyang approximately half of the time. For cities without central heating systems, the interior temperature fluctuated between 10 and 22 °C in Shanghai, between 5 and 12 °C in Chongqing, between 10 and 22 °C in Kunming, between 11 and 23 °C in Shenzhen, and between 14 to 23 °C in Nanning. The interior thermal environments of Shanghai were improved by individual heating systems, compared with those of Chongqing.

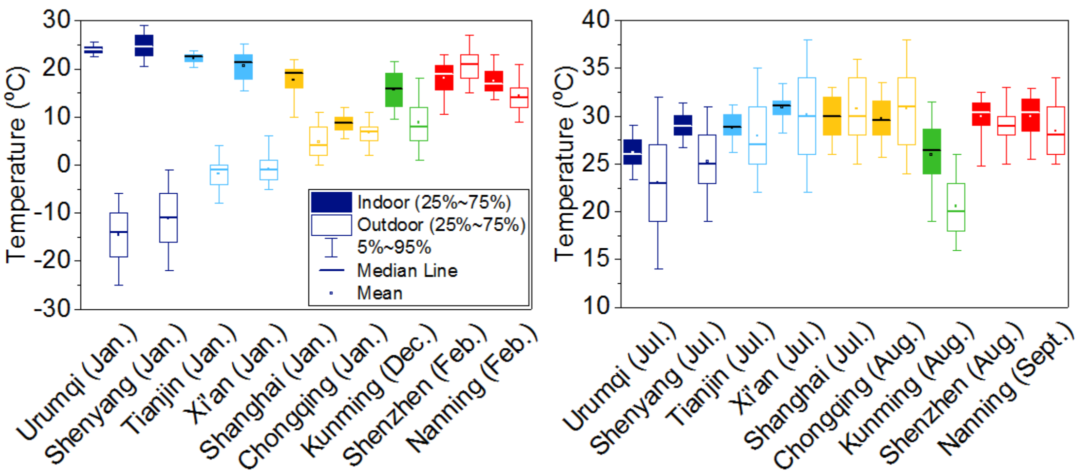

Figure S1. Box plots of the indoor and outdoor temperatures of the monitored apartments (a) in the coldest month and (b) in the hottest month.

In the hottest month, the exterior temperature varied over a wide range, which was probably due to the large diurnal temperature variation, especially for inland cities. For comparison, the interior temperature varied over a narrower range than its outdoor counterpart. The peak value was 29 °C in Urumqi; 31 °C in Shenyang, Tianjin and Kunming; 33 °C in Xi'an, Shanghai, Shenzhen and Nanning; and 34 °C in Chongqing. Moreover, the average indoor temperature of Xi'an in the hottest month was 1 K higher compared to other cities with similar outdoor conditions.

S2 Monthly indoor and outdoor relative humidities

Figure S2 plots the monthly outdoor and indoor relative humidities of the studied cities during the measurement period. For Urumqi, as the outdoor humidity ratio fluctuated in a narrow range, dramatic annual variation of the outdoor temperature strongly affects the outdoor relative humidity. As shown in Figure S3, the outdoor relative humidity declined to 41% in May and increased to approximately 69% in December. However, the indoor relative humidity exhibited the opposite trend and varied from 23% to 40%. The indoor relative humidity in Shenyang, Tianjin, Xi'an and Kunming exhibited a similar tendency to the indoor humidity in Urumqi, which peaked in summer or autumn and dropped to the minimum value in winter. The trends of the indoor and outdoor relative humidities were unclear in Shanghai, Chongqing, Shenzhen and Nanning. The humidity was constantly high in these cities. The outdoor humidity varied from 60% to 90%, while the indoor humidity was in the range of 50% to 75%.

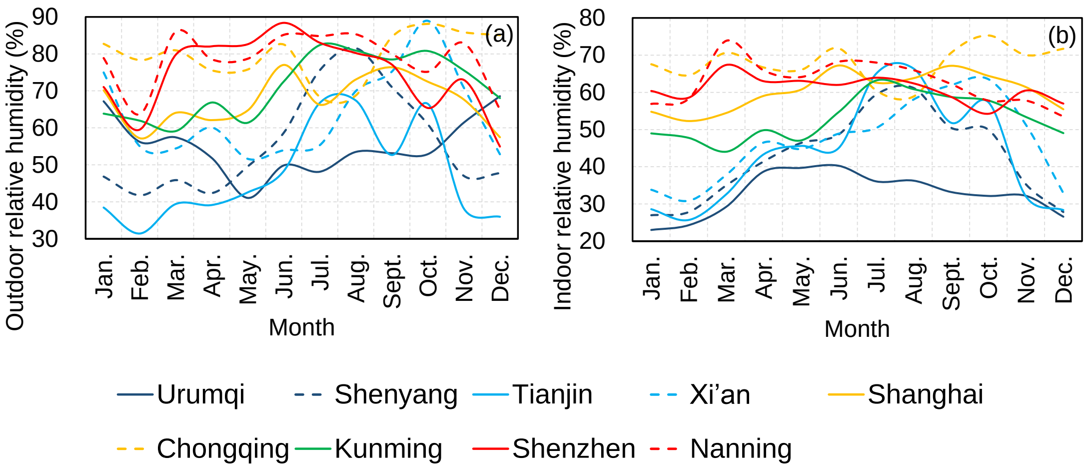

Figure S2. Summary of the monthly (a) outdoor relative humidity and (b) indoor relative humidity in the studied cities.

S3 Driest and wettest months

Figure S3 presents box plots of the outdoor and indoor humidity ratios in the studied cities for the driest and wettest months. As shown in Figure S3 (a), despite the increasing trend of the outdoor humidity ratio from north to south, the lowest indoor values do not differ substantially among the cities and range from 2.6 to 4.3 g/kg. The indoor humidity ratio of the HSWW region varied over a wide range from 3 to 13 g/kg, which was due to the influence of the outdoor humidity environment. In other cities, the maximum humidity ratio during the driest month was lower than 10 g/kg.

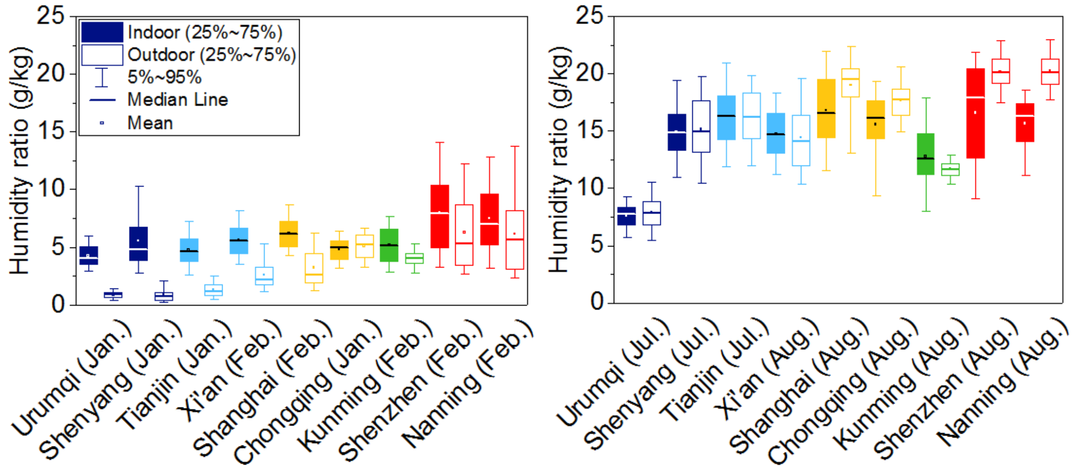

Figure S3. Box plots of the indoor and outdoor humidity ratios of the monitored apartments in (a) the driest month and (b) the wettest month.

In the wettest month, Urumqi has the lowest indoor and outdoor humidity ratios. The indoor and outdoor humidity ratios in the other cities exceeded 10 g/kg and were less than 23 g/kg most of the time. The indoor and outdoor humidity ratios did not differ substantially in Urumqi, Shenyang, Tianjin, Xi'an and Kunming during the wettest month. In the remaining cities, the interior humidity ratio was lower than the outdoor humidity ratio due to dehumidification of air conditioners. Moreover, the interior humidity ratios of Shanghai, Chongqing, Shenzhen and Nanning fluctuated over a wide range, which may be related to the differences in the use of A/C from day to day and among households.

S4 Evaluation of indoor thermal comfort

The indoor thermal condition is further evaluated based on both the static thermal comfort zone model and the adaptive thermal comfort model. The static comfort zones are different by seasons due to the varied thermal insulation of clothing, which is typically set as 0.5 clo in summer, 1.0 clo in winter and 0.7 clo in transitional seasons. Additionally, it is permissible to apply the static "comfort zone" to spaces where the occupants have activity levels that result in metabolic rates between 1.0 and 1.3 met and where the air speeds are not greater than 0.20 m/s [6]. Since residents' typical activities in bedroom was sleeping, seated and walking, the metabolic rate was defined as 1.1 met. And the air speed was defined as 0.1m/s. Mean radiant temperature equals to air temperature.

Figure S4.1 shows the evaluation results of indoor thermal environment based on the static thermal comfort zones. As shown in the figure, the indoor thermal environment is not well satisfied in most of the year. During the winter, the acceptable proportions were less than 0.5 in the cities without central heating systems. In summer, the acceptable proportions were even lower than 0.1 in those cities with high outdoor air temperature. During the transitional seasons, the average satisfied proportions varied from 0.2 to 0.6 in most dwellings.

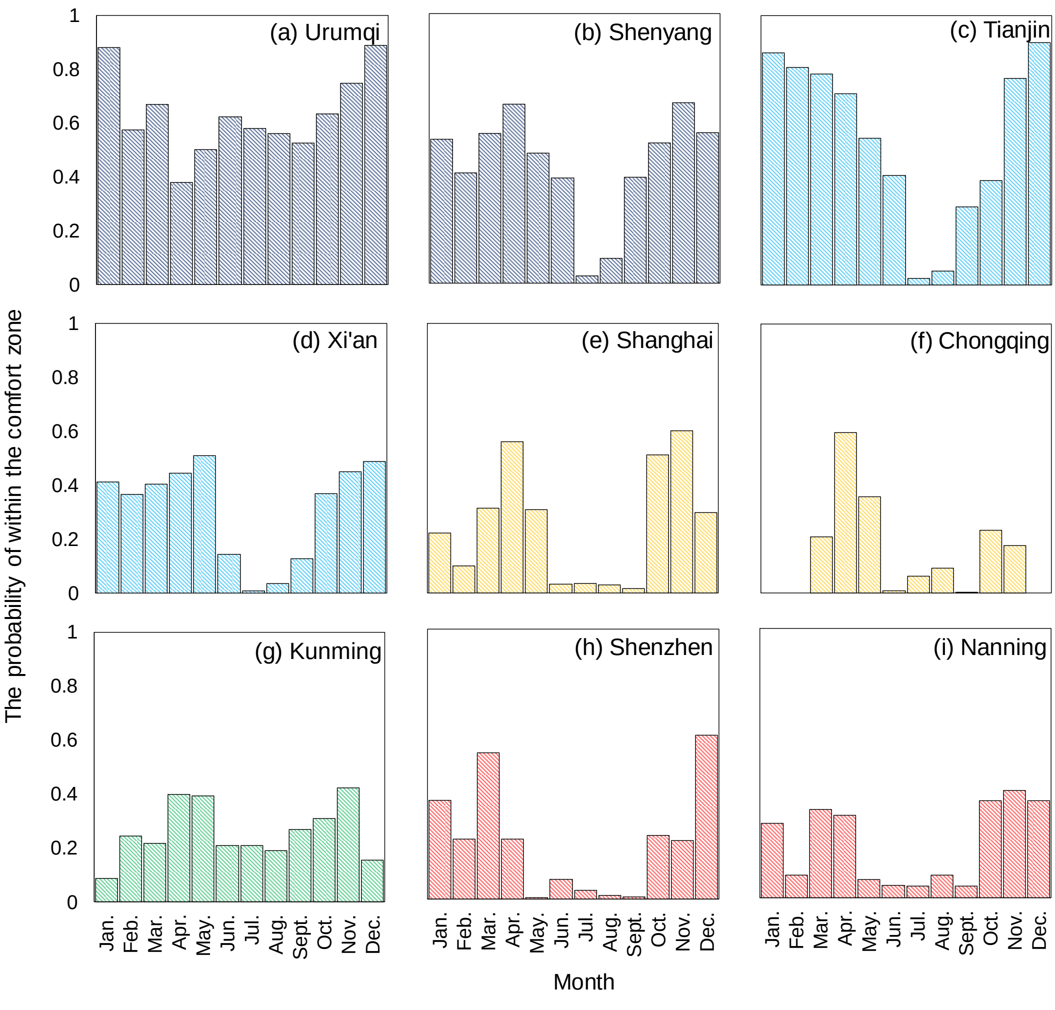

Figure S4.1. Evaluation of indoor thermal environment based on the static thermal comfort zone in: (a) Urumqi, (b) Shenyang, (c) Tianjin, (d) Xi'an, (e) Shanghai, (f) Chongqing, (g) Kunming, (h) Shenzhen, (i) Nanning.

Figure S4.2 shows the evaluation results of indoor thermal environment based on the adaptive model for 80% acceptability. The application of adaptive model requires the outdoor air temperature to be between 10 °C and 33.5 °C. Therefore, in winter, the adaptive model could only be applied to the evaluation of the indoor thermal conditions in Shenzhen and Nanning. The thermal conditions were acceptable during over half of the winter in these two cities. During the summer, the acceptable proportion in Urumqi was over 0.8, higher than the other cities (0.5 ~ 0.7). During the transitional seasons, the acceptable proportions varied from 0.58 to 0.88 in different cities.

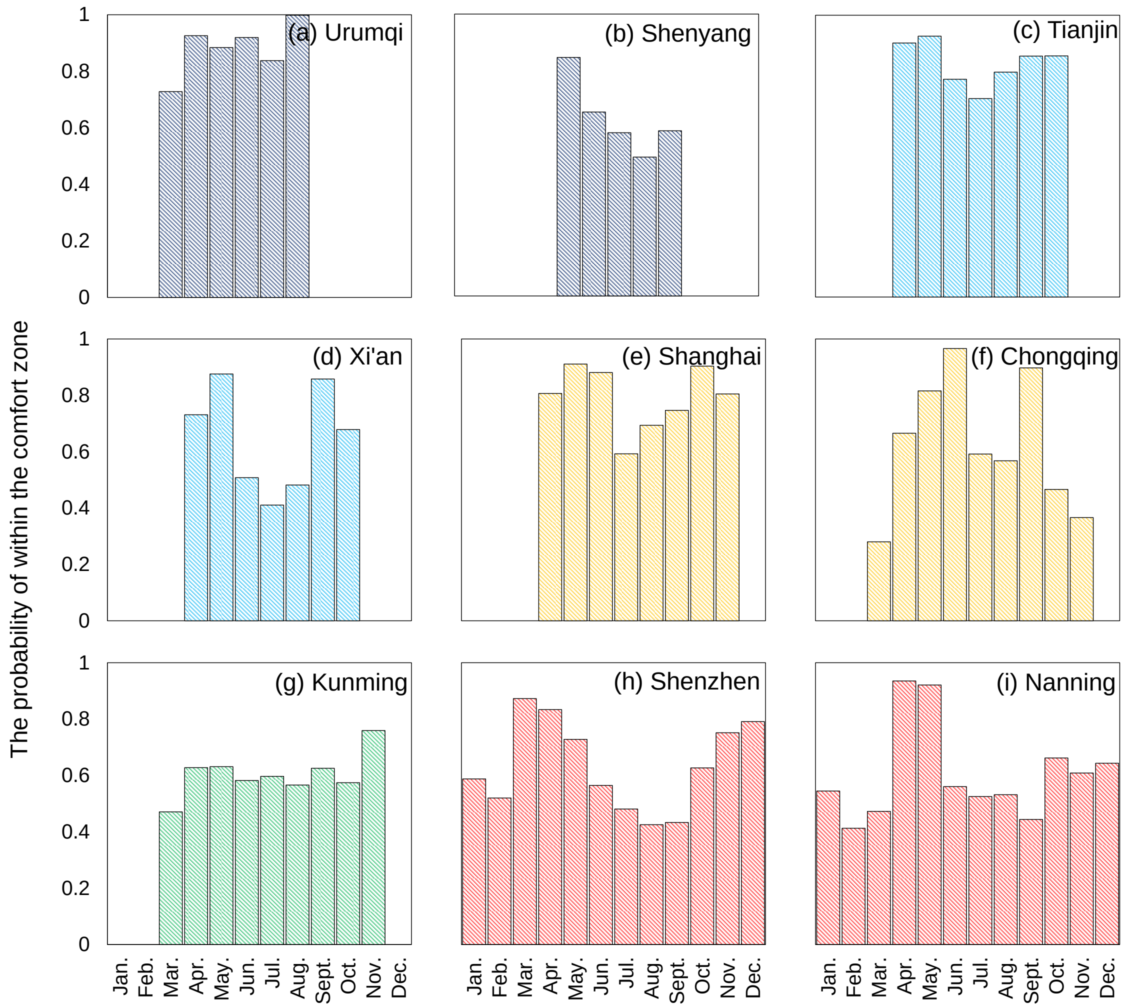

Figure S4.2. Evaluation of indoor thermal environment based on the adaptive model [6] for 80% acceptability in: (a) Urumqi, (b) Shenyang, (c) Tianjin, (d) Xi’an, (e) Shanghai, (f) Chongqing, (g) Kunming, (h) Shenzhen, (i) Nanning.

S5 Evaluation of indoor humidity environment

In consideration of thermal comfort, the upper limit of humidity ratio is 12g/kg according to the ASHRAE standard [6]. Figure S5.1 presents the time proportions of indoor humidity ratio values that could meet the ASHRAE Standard. The acceptable proportions of the humidity ratio were typically lower during the summer and higher in winter. In most cities, the acceptable proportions were generally lower than 0.2 from June to September. The high humidity problem was more serious in the southern cities. The indoor humidity condition in Kunming was slightly better, with the lowest proportion of 0.4 in August. In Urumqi, the indoor humidity ratio was acceptable through the whole year, which was caused by the dry climate.

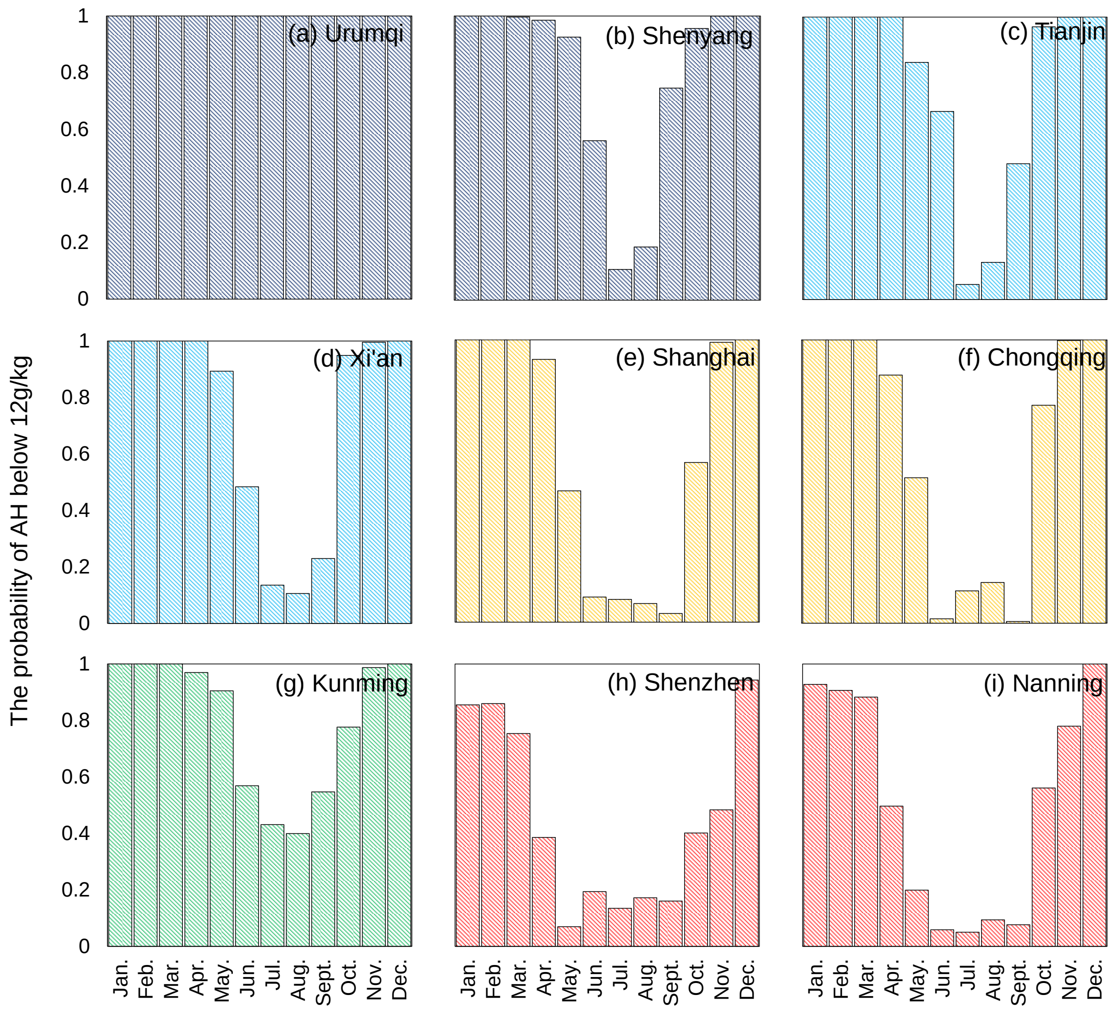

Figure S5.1. Evaluation of indoor humidity ratio according to the ASHRAE thermal comfort standard [6] in: (a) Urumqi, (b) Shenyang, (c) Tianjin, (d) Xi’an, (e) Shanghai, (f) Chongqing, (g) Kunming, (h) Shenzhen, (i) Nanning.

The optimum relative humidity is suggested to be in the range of 40% to 60% [1], in order to minimize adverse health effects. According to this criterion, the evaluation results of indoor relative humidity conditions were presented in Figure S5.2. The acceptable proportions in Urumqi were up to 0.5 in summer, but decreased to zero in winter. The acceptable proportions of Shenzhen and Nanning could be up to 0.6 in December and dropped to 0.1 in March. The curves of acceptable proportions also showed large variations with two peaks in Shenyang, Tianjin and Xi’an. Though having similar indoor humidity ratio, the satisfied proportions in Chongqing was lower than those in Shanghai, caused by the lower indoor temperature during winter. As for Kunming, the indoor relative humidity was acceptable for more than half a year, which was better than the other cities.

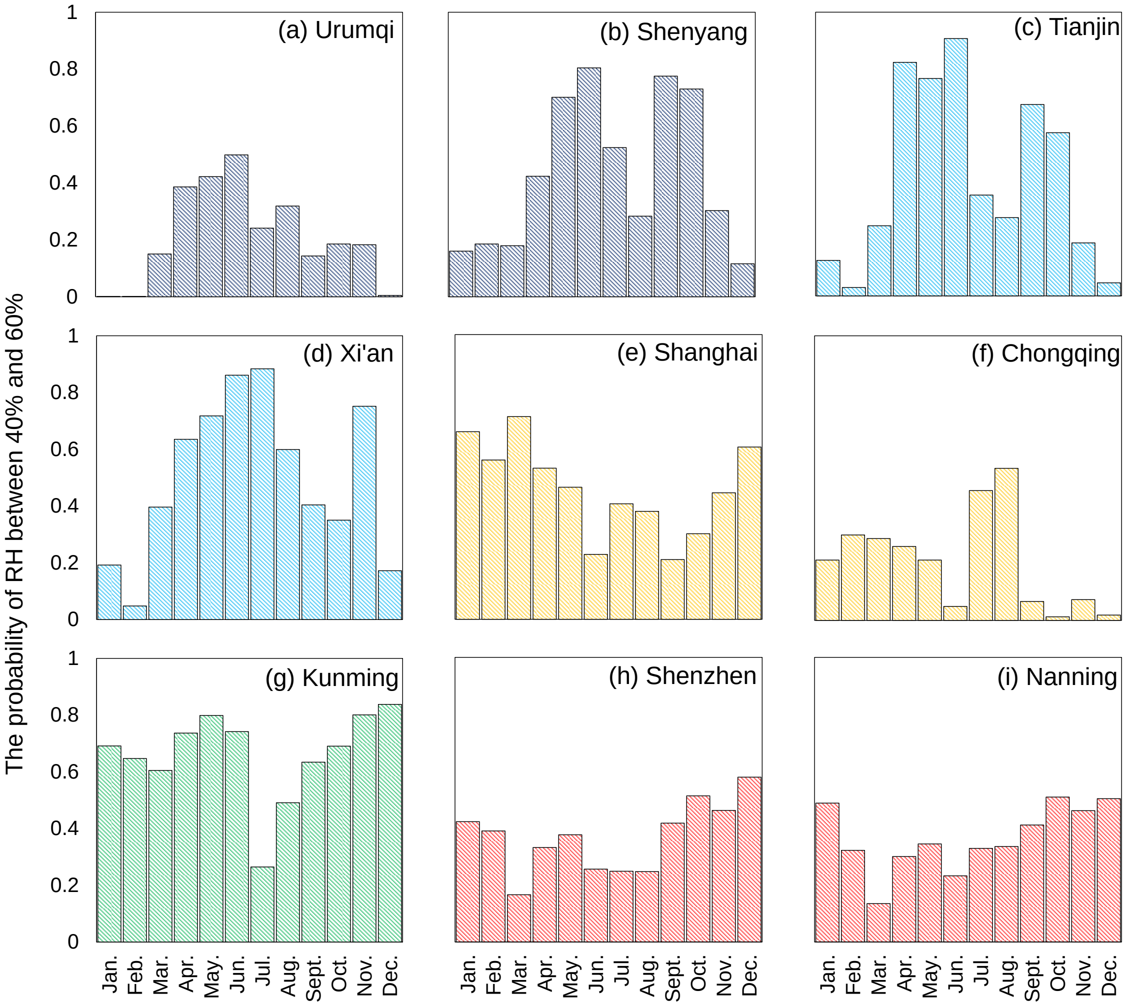

Figure S5.2. Evaluation of indoor relative humidity in terms of health effects [1] in: (a) Urumqi, (b) Shenyang, (c) Tianjin, (d) Xi'an, (e) Shanghai, (f) Chongqing, (g) Kunming, (h) Shenzhen, (i) Nanning.