Analysis of thermal comfort in residential buildings in the city of Ha Tinh, Viet Nam

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Abstract. The study was performed in Ha Tinh city of Vietnam and aims to investigate the current thermal condition inside houses of different urban neighborhoods by field measurement and survey. This is a starting point to develop sustainable housing and neighbourhood typologies as adaptation to climate change in the city. The survey was conducted in the summer of 2016. The analysis of the survey data showed that the satisfaction level of local inhabitants with actual thermal condition was relatively high, and the perception of those living in various neighborhoods did not differ significantly. To monitor the comfort level during summer in houses of Ha Tinh city, nine houses were selected based on their typologies and locations represented by local climate zones (LCZs). The investigation was conducted from late August to mid-October 2017. With data obtained from the field measurement, psychrometric analysis was performed and based on modified adaptive comfort model for South-East Asian people to evaluate thermal condition of considered houses. The analysis evaluated and showed explicit difference in comfort level between these housing typologies. Result of the analysis also showed a dependence of thermal comfort in different rooms of a house on their position and exposition to solar heat gained, but relation of comfort level to LCZs was not clear.

1. Introduction
The city of Ha Tinh is urban part of Ha Tinh province in the Northern region of Central Vietnam. Located at the latitude of 18 [1], Ha Tinh lies on tropical monsoon climate zone as classified by Koppen-Geiger [2] and climatic region I0 of Vietnam [3]. Its climate is prevailed by the extremely high amount of solar radiation and is typically exposed to hot-dry wind in summer [3]. In recent years, the city has been suffering from more intensive harsh weather conditions including heat stress and typhoons [4] due to impact of climate change while its resilience requires more improvement under the pressure of economical and spatial growth [5].

Various efforts in technical and academic fields have been made to provide solutions to these issues, including the research project WAMADE (Water Management and urban Development) [6] which, from the perspectives of hydrology and urban studies, researches the urban development of Ha Tinh city in relation to climate change and provides scientific support in the form of tools to develop sustainable development plans.
The fulfillment of the aforementioned objectives requires not only studies at large urban and neighborhood scale, but also those at housing level since houses are fundamental elements for the composition of urban areas. In order to improve resilience and sustainability of urban-areas, housing typologies should be developed in a way that brings their occupants thermal satisfaction while at the same time reduces power consumption. Such developments could only be properly realized when investigation of existing thermal condition of houses as a starting point is conducted. Therefore, a measurement- and survey-based research to provide insight into the current condition of houses in studied city and their effects on the occupants has been conducted. From this research, further studies can be conducted towards the improvement of thermal comfort and sustainability of buildings and neighborhoods.

The aim of this paper is to present results of measurements and survey on thermal comfort of houses in Ha Tinh city. At first, the method section explains the principle of houses selection and describes how the measurement was performed. Also in this section, basis for the evaluation of thermal comfort is introduced. The next part of the paper shows key results of surveys and measurements, and from the result, findings are drawn and used as uptake for the evaluation of thermal comfort levels in these houses.

2. Method
At first, a number of different housing typologies in the city were chosen. During almost two months of 2017 (from late-August to mid-October), field measurements were conducted at the location of the selected houses in order to obtain more insight in actual thermal condition of the houses in summer time. The evaluation of thermal comfort level was done by a psychrometric analysis. An additional analysis was made with data from survey taken in different neighborhoods in Ha Tinh city [7] in 2016, which provides information of dwellers’ thermal perception during the whole year. In this section, the principle of house selection and the method to assess thermal comfort by measurements and surveys are described.

2.1. Selection of houses
The determination of houses played an important role to the relevance of the study. The first selection criterion was the deviation between neighborhoods of the city which were identified according to the local climate zone (LCZ) scheme developed by Stewart and Oke [8]. The second criterion was the housing typologies which are characterized by numerous factors including function (used for either only dwelling purpose or combined with business), arrangement (detached or terraced), number of floors (having only 1 or 2 to 4 floors), shape of roof (pitched, flat, or combination of pitched and flat roof), the presence of a shed, and finally wall materials (bricks and cement, raw earth with straw or concrete).

| LCZs | Description (Built/ land cover type) |
|------|--------------------------------------|
| LCZ3 | Compact low-rise: Dense mix of low-rise buildings (1-3 stories); Few or no trees; Land cover mostly paved; Stone, brick, tile and concrete construction materials |
| LCZ6 | Open low-rise: Open arrangement of low-rise buildings (1-3 stories); Abundance of pervious land cover (low plants, scattered trees); Wood, brick, stone, tile and concrete construction materials |
| LCZ9 | Sparsely built: Sparse arrangement of small or medium-sized buildings in a natural setting; Abundance of pervious land cover (low plants, scattered trees) |
| LCZA | Dense trees |
| LCZB | Scattered trees |
| LCZD | Low plants |
| LCZG | Water |

In the study on LCZs of Ha Tinh city [9], seven LCZs were identified and denominated as LCZ3, LCZ6, LCZ9, LCZA, LCZB, LCZD and LCZG based on the difference in built and land cover type.
The first three zones followed by a number (LCZ3, 6 and 9) were recognized by the property of built land while the other four were classified by types of land cover. This research only focused on the zones LCZ3, 6, and 9 where the variety of housing density and typologies were significant and therefore could have feasible effect on indoor thermal comfort. Description of LCZs is found in Table 1.

For the next step, typical housing typologies should be determined based on functional and physical properties. The study followed the housing typologies classification [7], but made modification so that all selected houses were single-family houses and functioned as dwelling place without incorporating business activity (house only). Finally, nine typical typologies in three LCZs were chosen for field measurement and each typology was named in abbreviation form presenting functional and physical properties. For example, typology 1 was labeled as HSO2-4PS to explain that it was used for Housing purpose only, was in Semi-Open arrangement, with number of stories in between 2 - 4 (3 stories), Pitched-roof structure and attached with a Shed. Table 2 provides details of selected houses for this study. Positions of measured houses were shown on the map of the city on which LCZs were illustrated (see Figure 1).

| House | Picture | Detailed description of typology | Typology | LCZ |
|-------|---------|---------------------------------|----------|-----|
| 1     |         | Used for Housing purpose only, Semi-Opened, 3 floors, Pitched roof, Shed attached | HSO2-4PS | LCZ3 |
| 2     |         | Used for Housing purpose only, Semi-Opened, 1 floor, Flat roof, No Shed attached | HSO1FNS | LCZ3 |
| 3     |         | Used for Housing purpose only, Terraced, 3 floors, Flat roof, No Shed attached | HT2-4FNS | LCZ6 |
| 4     |         | Used for Housing purpose only, Detached, 1 floor, Pitched roof, Shed attached | HD1PS | LCZ6 |
| 5     |         | Used for Housing purpose only, Detached, 2 floors, Pitched roof, Shed attached | HD2-4PS | LCZ9 |
| 6     |         | Used for Housing purpose only, Terraced, 2 floors, Pitched roof, Shed attached | HT2-4PS | LCZ3 |
| 7     |         | Used for Housing purpose only, Terraced, 1 floor, Pitched roof, Shed attached | HT1PS | LCZ9 |
| 8     |         | Used for Housing purpose only, Terraced, 3 floors, Pitched roof, Shed attached | HT2-4PS | LCZ9 |
| 9     |         | Used for Housing purpose only, Detached, 2 floors, Pitched roof, Shed attached | HD2-4PS | LCZ6 |
2.2. Field measurement and psychrometric analysis

The measurement was performed from late-August till mid-October 2017, and the main goal was to evaluate the summer comfort in selected houses. Psychrometric analyses are the backbone of the assessment, but their distributions are influenced by the utilized comfort model. In the study, the modified adaptive model for South-East Asian people introduced by Nguyen [10] was adopted as basis for analysis and evaluation. Nguyen re-defined the different comfort zones on the building psychrometric chart in accordance to actual adaptation and response to climate of Vietnamese people (see figure 2). The comfort level was indicated by the comfort temperature ($T_{\text{comf}}$) which was given in the relation with mean outdoor air temperature ($T_{\text{out}}$) through equation (1):

$$T_{\text{comf}} = 0.341 \times T_{\text{out}} + 18.83 \degree \text{C}$$  \hspace{1cm} (1)

The value of $T_{\text{out}}$ can be taken as the arithmetic average of the mean daily minimum and the mean daily maximum outdoor (dry bulb) temperature of a month; however, the values of $T_{\text{out}}$ which have been used for this research were actually taken from logged data in individual local climate zones, rather than the ones collected from local weather station. Besides the value of $T_{\text{comf}}$ as comfort indication, the assessment was further performed using the Building Psychrometric chart analysis with basic comfort zone and extended ones (by application of natural ventilation).

The measurement was designed and performed with temperature and humidity data loggers (Velleman DVM171THD loggers) to obtain data on operative temperature during summer at locations.
inside and around selected houses. The accuracy of the measurement for air temperature and relative humidity can be found in Table 3.

**Table 3. Characteristics of Velleman DVM171THD loggers.**

|                          | Overall range | Accuracy                     |
|--------------------------|---------------|------------------------------|
| Relative humidity        | 0 - 100 % ± 5.0 % | (0 % - 20 % and 80 % - 100 %): ± 5.0 % |
| measurement             |               | (20 % - 40 % and 60 % - 80 %): ± 3.5 % |
|                         |               | (40 % - 60 %): ± 3.0 %       |
| Dry-bulb temperature    | -40 °C to 70 °C | (-40 °C to -10 °C) and (+40 °C to +70 °C): ± 2 °C |
| measurement             |               | (-10 °C to +40 °C): ± 1 °C   |

For outdoor measurements, the sensors were protected against direct sunshine by radiation shields as recommended in the Guide to Meteorological Instruments and Methods of Observation [11]. Inside each house, various measurements were simultaneously conducted in most of the rooms during 4 days, see example in Figure 3 with all measurement locations in house 7.

![Figure 3. Plan layout of house 7: the measurement locations are indicated by red dots.](image)

However, due to the limited availability of loggers, only two among nine selected houses could be measured in the same period. Unfortunately, the planned measurement in house 5 could not be realized due to the occurrence of a severe storm. The ‘as-performed schedule’ is shown in table 4.

**Table 4. Schedule of on-site measurement.**

|                  | 24-30/8/2017 | 30/8-5/9/2017 | 6-12/9/2017 | 21-28/9/2017 | 28/9-5/10/2017 |
|------------------|--------------|---------------|-------------|--------------|----------------|
| Outdoor temperature (°C) [13] | 28.5-33.8   | 32.8-36.5   | 33.4-37.4   | 29.4-32.9    | 26.4-32.9      |
| Houses           | 1&2          | 3             | 4           | 6&7          | 8&9            |

2.3. Survey
In addition to the measurements, the evaluation of indoor comfort in the houses was complemented by surveys of thermal comfort perception by dwellers. The survey was already conducted as a part of
previous study [6]. The questionnaires were handed out to 120 families in 4 different neighborhoods of the city (shown in Figure 4), and covered questions related to how people experienced the thermal environment inside the houses in both summer and winter. There was one representative of each family to answer the survey questions. To help the participants determine their satisfaction in two different seasons, a thermal comfort scale was derived from the psychological comfort model of Fanger [12] and represented by a specific indicator ranging from -2 to +2 in correspondence with resulting feeling from “very cold” to “very hot”.

3. Results
In this section data are discussed on occupants’ comfort level in summer and winter which were obtained from the survey in 2016, as well as results of the measurement of air temperature and relative humidity in selected houses in summer of 2017.

3.1. Results of survey of thermal comfort perception
Figures 5 to 8 show the thermal comfort perception by dwellers in summer and winter season. The results indicate that in general, indoor temperature provided a majority of inhabitants with satisfaction: 55 to 62% of the questionnaire participants classify the mean indoor temperature as in neutral situation in both winter and summer. However, almost one third (37%) of the inhabitants perceived the thermal condition in winter as too cold (-1 to -3) and 25 to 30% perceived it as too hot in summer (+1 to +3). If a reduced scale of comfort (-2/+2) was applied, a similar perception was provided by occupants.

The seasonal mean values were determined separately for both comfort scales. For the reduced scale, median-based seasonal values in winter and summer were 0.6 and 0.5 respectively. With the normal scale (-3/+3), the value for summer was 0.8 while that of winter was 0.9. This confirms the conclusion that the majority of the inhabitants are satisfied with the indoor temperature during summer and winter.

The thermal comfort perception was further examined in relation to the location of the houses in the local climate zones. In general, uniform pattern of occupants’ perception revealed not a feasible correlation between LCZ and thermal perception. Only a more visibly neutral state in winter perceived in LCZ3 was shown in Figure 8 when using the normal scale (-3/+3), [12]. It was an interesting result because LCZ3 is most densely paved with high density of low-rise houses and other buildings, and it could have been thought to bring less comfort than neighborhoods of other LCZs.
Figure 5. Perception temperature in winter of 120 surveyed participants with full comfort scale (-3/+3)

Figure 6. Perception temperature in summer of 120 surveyed participants with full comfort scale (-3/+3)

Figure 7. Perception temperature in winter of 120 surveyed participants with reduced comfort scale (-2/+2)

Figure 8. Perception temperature in summer of 120 surveyed participants with reduced comfort scale (-2/+2)

Figure 9. Comparison of thermal perception (average value of scale -3/+3) between location in different LCZ

Figure 10. Comparison of thermal perception (average value of scale -2/+2) between location in different LCZ
3.2. Results of temperature and relative humidity measurement

Figure 11 shows the measurement results of the actual temperature in house 1 as an example together with the threshold values of comfort temperature $T_{\text{comf}}$.

Psychrometric analysis for house 1 was also performed, and it is presented in Figure 12. The figure shows that indoor comfort of the house varied with different outdoor condition temperature, and duration when rooms of the house were exposed to discomfort was longer than it was as shown in figure 11 in which only air temperature was taken into account. The difference was due to the combining influence of relative humidity with temperature, causing unexpected comfort to the occupants. The analysis also indicates that the bedroom of house 1 was exposed to more discomfort than the other rooms. This can be explained by the difference in positions of the rooms in measured house: the living room is on the ground floor where least solar heat is transferred while the bedroom is on the first floor and closed to the roof structure, which gains high amount of solar heat during the daytime.

Figure 11. The statistic of air temperature variation in locations of house 1 during measurement time in comparison with values of comfort temperature

Figure 12. Result of psychrometric analysis for house 1 during four days of measurement.
Similar analyses were conducted with the measurement data in all the selected houses (except for house 5). A summarized statistic of comfort levels in all houses is given in Figure 13. Despite the fact that not all measurements were conducted at the same time, and therefore were influenced by unequal outside weather conditions, the comparison forms a basis for the evaluation of indoor thermal comfort level. The figure shows there was a high level of discomfort in houses 1, 3 and 4 while indoor climate in the other houses was significantly less out of comfort range.

The difference can be explained by the fact that houses with more openings and surrounded by less buildings (houses 2, 6, 7 and 9), or the ones structured with double-layered roof as well as ventilated roof (houses 8 and 9) enable higher comfort percentage, while most discomfort houses (1, 3 and 4) are located in more populated quarters or closely surrounded by neighboring houses, which may obstruct ventilation cooling during summer time.

An unexpected result was detected in the measurement for house 3 where discomfort state was dominating. In fact, the house design was studied with sustainable climatic approach in expectation to achieve high level of comfort, and the real comfort in the house was also recognized by its occupants. The counter-intuition can be argued by the influence of harsh outdoor condition while conducting measurement, the inefficiency of novel vegetated roof, and large amount of solar heat penetrated through glass vanes on its main facade. One more reason for the discomfort situation is related to Southwest orientation of the house in which unpleasant Foehn hot-dry wind flow was prevailing in the summer and probably during the whole measurement time.

4. Conclusion

This paper presents the results of measurements and surveys on thermal comfort in residential buildings in Ha Tinh (Vietnam). According to what the survey found, the majority of local people was satisfied with the operative temperature in both seasons. The survey also presented various perception of inhabitants from different LCZs of the city, though the deviation was not significant. Besides, it gave an unexpectedly positive results in actual satisfaction of dwellers in most compact LCZ (LCZ3).

The results from measurements of operative temperature and relative humidity provided more detail about comfort level achieved in different housing typologies in the city, and indicated the dependence of thermal condition on properties of building envelope and natural ventilation efficiency. In the majority of measured houses, the comfort state could be achieved in most of the rooms by cross ventilation while natural comfort feeling could only occur in a very short duration of the measurement.

The study provides a clear insight on thermal condition of houses in Ha Tinh city and perception of local inhabitants from different parts of the city, and its results could be used as starting points in further
studies for improvement of houses in terms of thermal condition and energy efficiency. For research at larger scales of neighborhood and urban areas, the study can contribute to the development and/or improvement of neighborhood typologies in complementation to typologies of buildings for a better climatic adaptation and thermal environment.

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