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Thermal comfort in primary school classrooms: A case study under subarctic climate area of Sweden

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ABSTRACT

Limited studies were focused on primary school buildings especially under subarctic climate. Thermal comfort of children was assumed to be similar as that of adults, which may cause inaccuracy. To fill data blank and enrich global database, a field study was performed from late fall 2016 to early spring 2017 covering whole heating period in north part of Sweden. Indoor CO_2 concentration was continuously monitored to evaluate indoor ventilation. Thermal comfort related parameters were continuously measured and predicted mean vote (PMV) was calculated. Subjective questionnaire surveys were performed every week except holidays. Subjective thermal sensation value (TSV) was always higher than objective PMV, which reflected thermal adaptation. The thermal adaptation became not obvious in middle and late winter because of long term exposure to heating environments. Heating system should be intensified gradually in early heating period, operated based on actual outdoor climate instead of experience in middle and late heating periods, extended under part load operation in early spring if necessary. The new 13—point TSV scale was pointed out by other researchers and tested inthis study, which can explore tiny TSV deviations from thermally neutral status and reflect more accurate thermal sensations.

1. Introduction

Based on thermos-physiological approach [1–3], thermal comfort studies were extensively performed before adaptive thermal comfort approach was pointed out [4,5], which emphasized to actively adapt to environments instead of passively accept. Adaptation process depends on context, thermal history and expectation. A lot of field studies, mainly in office buildings and residential buildings, were performed under different climatic zones [6–14] and a global database of field studies was developed [15].

Findings from above mentioned field studies formed the basis of different thermal comfort standards including ISO 7730 [16], ASHRAE standard 55 [17] and European standard EN 15251 [18]. Determinants of thermal comfort were assumed to be similar for both children and adults and findings based on adults were used directly. However, metabolic rate, clothing and limited adaptive behavior of children may cause differences [19,20]. Limited studies focused on institutional buildings, especially primary schools with young occupants. Limited data were obtained under tropic climate [21], subtropic climate [20,22], dissert climate [23], Mediterranean climate [24,25] and temperature climate [26–29]. According to authors' knowledge, no field study was performed in primary schools under subarctic or arctic climate. Although limited adaptive behaviors can be used under subarctic or arctic climate, compared with other climates, adaptive thermal comfort and the influence of thermal history were analyzed in University classrooms and dormitories under severe cold climate [30,31]. Therefore, it is necessary to perform thermal comfort field studies in school buildings under subarctic climate because environmental quality of a classroom influences not only comfort and health, but also working and learning efficiency [32–34].

Compared with data measured and calculated by Fanger static method, big differences were found in thermal sensation votes (TSV) which are based on 7—point scale. A high percentage of subjects prefer slightly warm or slightly cool when 0 were chosen in TSV. As a solution, 13—point scale was pointed out to give subjects more options especially when their TSV slightly deviate from neutral [35,36]. Only limited data, mainly obtained in University classrooms in Italy under Mediterranean climate, were used to validate the feasibility of the new thermal sensation scale. The data, obtained in primary school classrooms under subarctic climate area of Sweden, can also be used to test

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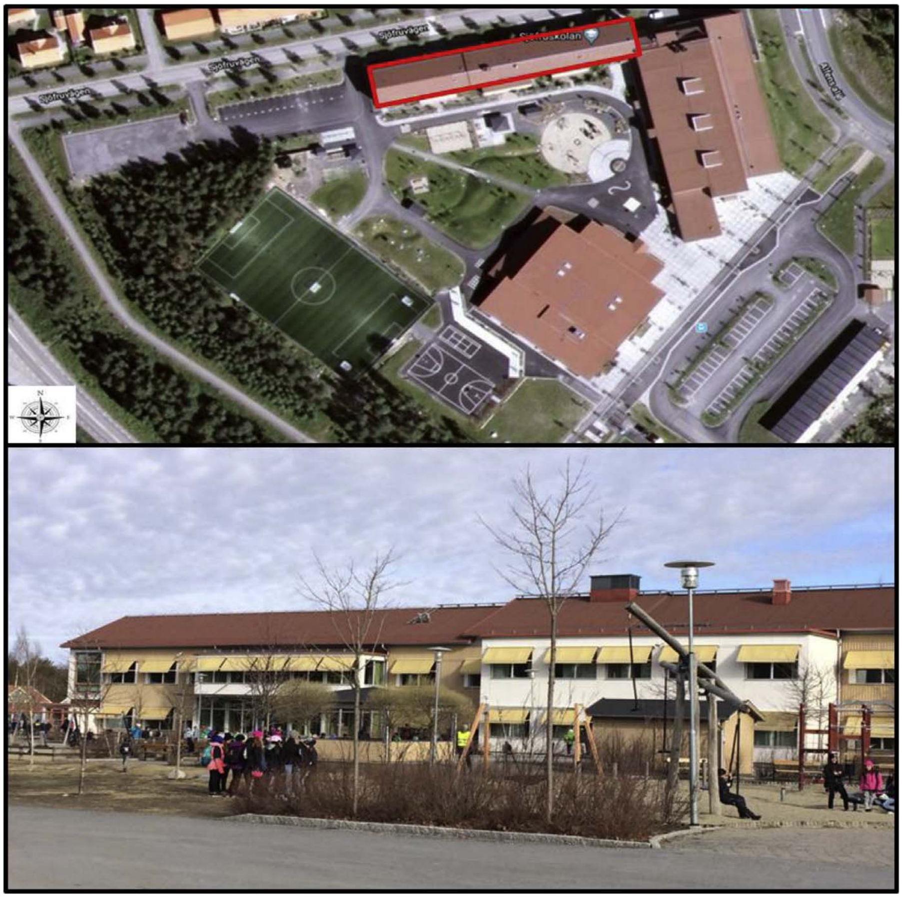

Fig. 1. Diagrammatic plan and photo of the Primary school (Sjöfruskolan) in Umeå, Sweden.

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2. Research methods

2.1. The case study school

The case study school is shown in Fig. 1. The L-shape main building is separated into two parts. Classrooms are mainly located in the area marked with a red rectangular, which is near North—South orientation. Big atrium with indoor entertainments such as table tennis and billard ball, teachers' offices, conference rooms, kitchens and canteens are located in the parts with near West—East orientation. The architectural paln is shown in Figs. 2 and 3.

The school (Sjöfruskolan) building is located in Tomtebo, Umeå, Sweden. It is a public elementary school with 600 pupils aging from 6 to 16 years old. The school is owned and operated by Umeå municipality. The inaugurated of the school was in 2002. Due to expansion of city district, the school was soon found too small and it was extended to the present size in 2008 with the floor area 5160 m^2 and building cubic volume 17,250 m^3. The buildings were constructed by 150 mm concrete slabs. The on-ground floor slab was casted on a 100 mm foam insulation. The building consists of two stories, with a room height of 3.2 m. The top roof slab is of prefabricated concrete, covered with 400 mm mineral wool under a pitched roof construction of wood. The load-bearing frame is wood and steel column construction complemented with concrete walls for stabilization. From the outside to the inside, the gable walls were made of 12 mm facade panel, 12 mm air gap, wind stopper, 195 mm mineral wool and 150 mm concrete. The long-side exterior walls were constructed in a similar manner as the gable walls, but steel columns replace the load-bearing concrete and the interior layer is a 14 mm gypsum board. Windows are triple-glazed (Fig. 4).

The heat transfer caracteristics are as follows. U-value of wall, roof,

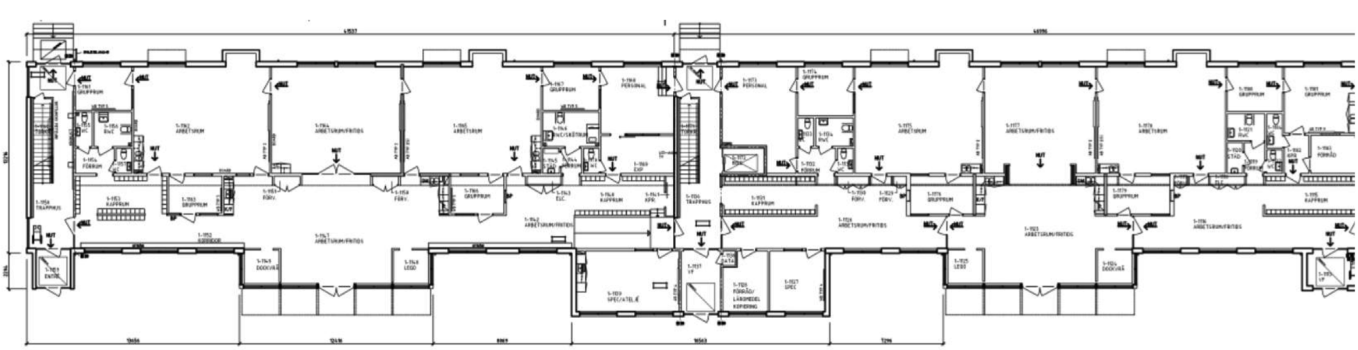

Fig. 2. Plan with the investigated class rooms, first floor.