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NUMERICAL ANALYSIS OF TEMPERATURE AND AIR STREAM VELOCITY DISTRIBUTIONS IN THE CROSS-SECTIONS THROUGH A ROOM WITH A BOOK COLLECTION

Abstract
The aim of the study was to analyze selected parameters of air in a room with a book collection taking into account the influence of components of mechanical ventilation on air flow, temperature and velocity distributions. The values of air parameters, obtained by numerical calculations in DesignBuilder, were compared with the recommended ranges. The temperature and air velocity in the cross-sections through the part of the room with the book resources were referred to the prescriptions and standards relating to the conditions in libraries. The parameters of air in the space for permanent stay of employees were compared with the guidelines corresponding to the conditions of thermal comfort.

Key words
CFD modelling, air parameters, conditions in library, thermal comfort

Introduction

As far as libraries are concerned, they are buildings designed for gathering, storage and facilitating paper book, acts, documents as well as manuscripts, maps, parchment documents, films, photographic, audiovisual and other references [1]. Therefore, they need the proper thermal conditions in terms of book storage and the presence of people. Studies of air temperature, humidity and velocity in libraries were undertaken by several researchers [2 – 4] and recommendations for the air quality in the libraries were made [5 - 8]. What is more, the thermal conditions in the libraries become a subject of the international ISO 11799 [9] standard and related national PN-ISO 11799 [1] standard, where the criterions for acceptable air temperature and velocity were stated. Since the libraries are very similar to office rooms, the recommendations of the PN-EN ISO 7730 standard [10] concerning thermal comfort of people in the offices can be applied also to the libraries.

Guaranteeing the appropriate temperature, relative humidity and air quality in libraries reduces the risk of physical, chemical and biological destruction of resources. Fluctuations of air temperature that do not fulfil the requirements may result in the marring of paper and paste, as well as the condensation of moisture on the partitions and interior equipment, such as a metal rack. The values of relative humidity and temperature above the recommended levels can cause an increased growth of microorganisms, which can lead to the tincture of leaves. Good air quality in the libraries can be maintained by providing constant microclimate parameters and proper air circulations in the rooms, especially between the racks [7]. Therefore, the racks should be set at appropriate distances. In addition, the distance between the bottom shelf and the floor, as well the resources from the top shelf and the ceiling, should be 150mm [1].

The following parameters of air are recommended in libraries [8]:

- air temperature in the range from 20°C to 22°C,
- the velocity of the supply air below 0.13m·s-1,
- the number of air changes per hour from 8 to 12.

Rooms in libraries should fulfil the requirements, which involve inter alia climatic conditions as well as the permissible concentrations of pollutants, which are presented in the standard PN-ISO 11799: Information and documentation – Document storage requirements for archive and library materials [1]. During long-term storage of paper collection, which are often borrowed, and warehouses, where the employees are, the temperature should be in the range from 14°C to 18°C. On the other hand, the relative humidity can have a value between 35% and 50% [1]. In libraries, the employees are staying permanently. Accordingly, apart from the conditions for storage, the comfort should be taken into account.

Thermal comfort is a steady heat balance of the human body condition. It depends on parameters such as inter alia air temperature, air stream velocity, relative humidity and the average temperature of the building partitions surfaces [11 - 13]. The air temperature and velocity should be selected to include the type of use in these the rooms and the employee's activity [14]. Human feelings associated with air quality, beyond not providing thermal comfort, can be impaired by impurities from the building materials, bacteria, odors and gases, or carbon dioxide [15 - 16].

Activities carried out by the librarian are like office work. On this account, the table 1 presents the design criteria for office spaces for each category of building. There are the following categories of building: A – category fulfils the high requirements, B – category fulfils the average requirements and C – category fulfils the moderate requirements [10].

Table 1. The design criteria for the office spaces for the winter season

Category	**Temperature (℃)**	**Maximum air velocity ($m \cdot s^{-1}$)**
A	22.0±1.0	0.10
B	22.0±2.0	0.16
C	22.0±3.0	0.21

Source: [10]

Vertical and horizontal temperature fluctuations can also be a cause of discomfort. The temperature difference between the head and the feet should not exceed 3℃ [17]. The recommendations of the PN-EN ISO 7730: 2006 standard [10] for the vertical temperature difference are presented in the table 2.

Table 2. The air temperature difference in vertical between the head and ankle

Category	**The air temperature difference in vertical (℃)**
A	< 2
B	< 3
C	< 4

Source: [10]

Analysis of air parameters can be realized using computational fluid dynamics (CFD). The software which uses the CFD, enables the user to create geometric models, to enter the boundary conditions, to generate the grids and to perform the calculations [19]. Numerical methods facilitate an approximation of differential equations by simultaneous algebraic equations [20].

DesignBuilder [21] is a computer software that enables numerical analysis of air parameters in the building. It has a CFD module, which performs simulations of air flows inside and outside the building by solving the differential equations of the fluid stream using the finite volume method [22]. Results of the numerical calculations are presented with the distributions of temperature, velocity and thermal comfort indices.

Method description

The analysis of distribution of temperature and velocity of the air streams was carried out for the selected library room with a book collection. The room is placed on the first floor of the Library of the Lodz University of Technology in Lodz, Poland. The room has the surface area of $469.6m^2$ and contains two workstations with desktop computers for the librarians, two self-checkout stations to borrow books and six places with desktop computers to search the collection situated in the first part of the room. There are forty-seven shelves with books and a copy machine in the back part of the room. The book room has the central heating and supply mechanical ventilation systems. There are two air handling units of designed airstream of 3500m3·h-1 each, supplying the air to the first floor of the building. The air exhaust is supported by the roof fans.

The research method was undertaken in the two steps. Firstly, the experimental measurements of air velocity and temperature in the room were made to provide thermal and airstream boundary conditions for the numerical calculation and to provide a validation of CFD model. The second step was to make a geometric model, determine the boundary conditions and set up a numerical calculations using CFD method in the DesignBuilder software. The results of the CFD calculations were obtained in the form of cross-sections of the room with the air temperature and velocity distribution and the values were represented using adequate colours from blue (the lowest value) to red (the highest value).

When it comes to the experimental measurements, the airstream was calculated using the average velocity of the supply and exhaust air measured for 10 second using the vane anemometer with capture hood with 3% accuracy. The room's air temperature was measured in 21 points using the digital microclimate meter BABUC/A [23], containing of the psychrometric probe with ± 0.19^{o}C accuracy. The results were read after 3 minutes, after stabilization of the values and were used for the validation of the CFD model. The temperature of the radiators and internal surfaces was measured using the radiation pyrometer with ± 1.5^{o}C accuracy. The temperature of the supply air was measured using an industrial electronic thermometer with ± 0.1^{o}C accuracy.

Numerical analysis of air parameters was performed in DesignBuilder. The geometric model of the room was created in the program using 3-D modelling tool. The fig. 1 presents the geometric model of the book room with the particular system components marked as follows:

- R – radiator,
- S – supply air diffuser,
- E – exhaust air diffuser.

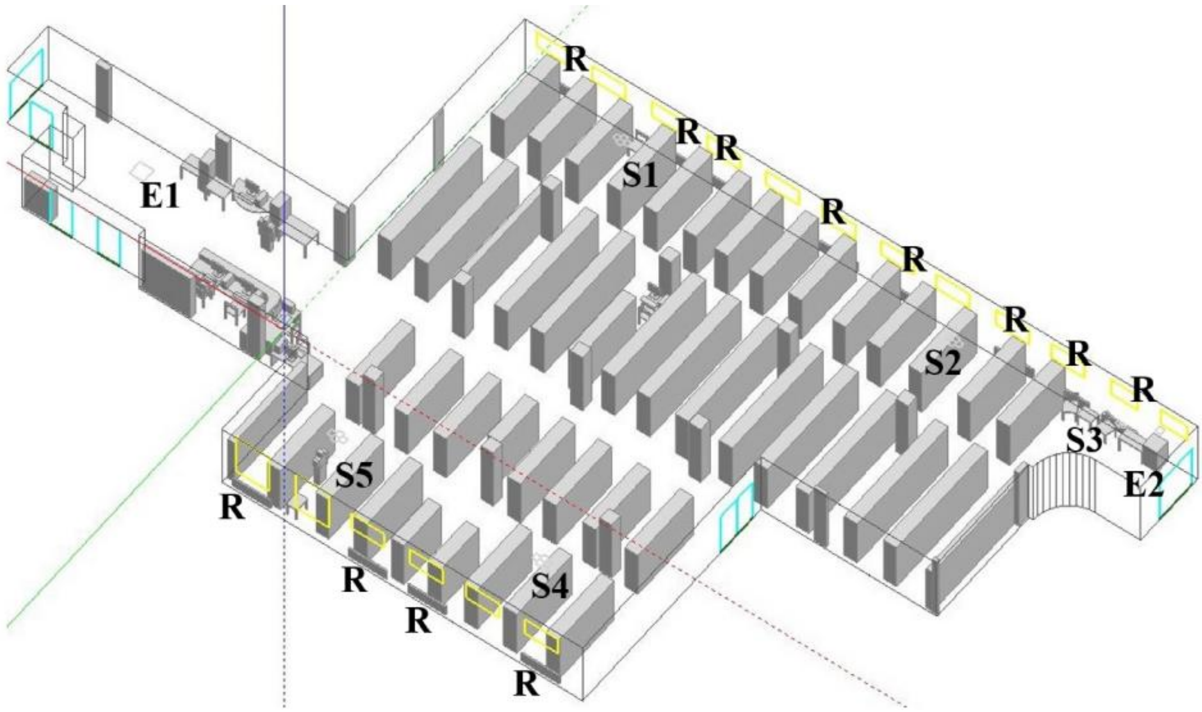

Fig. 1. The geometric model of the room with book collection
Source: Author's

The dimensions of room elements and the boundary conditions of the air parameters, such as temperature of the radiators, air stream and temperature of the supply and exhaust were input to the CFD model, based on the experimental measurements. The fig. 2 presents the thermal boundary conditions introduced in DesignBuilder. The temperature of the surfaces was obtained using radiation pyrometer and the temperature of the supply air was measured using an industrial electronic thermometer. As the radiators were out of operation due to the non-heating season, their temperature was only 21.5°C.

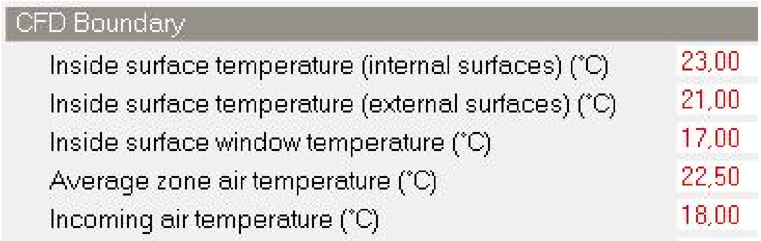

Fig. 2. The thermal boundary conditions introduced into the DesignBuilder
Source: Author's

As far as the boundary conditions of the air stream in the CFD model are concerned, the room is equipped with 5 air supply diffusers and 2 air exhaust diffusers located on the ceiling. There are two four-way supply air diffusers with the dimensions 469x469mm, which supply air respectively in the volume of $51 l\cdot s^{-1}$ and $56 l\cdot s^{-1}$, two four-way supply air diffusers with the dimensions 412x412mm, which supply air in the volume of $16 l\cdot s^{-1}$ and $18 l\cdot s^{-1}$, one four-way supply air diffuser with the dimensions 245x245mm, which supply air in the volume of $13 l\cdot s^{-1}$. The air exhaust is conducted through two diffusers, with the airstream respectively $58\ l\cdot s^{-1}$ and $12 l\cdot s^{-1}$. The airstream through the diffusers was measured using the vane anemometer with a capture hood.

After introducing the geometric model and the boundary conditions the CFD calculations were performed the DesignBuilder software with CFD module. Simulations of the air flow and thermal comfort parameters in the library were made for above 4000 iterations using "k-ε" turbulent and "Power Law" calculation model [22]. The CFD calculations allowed to obtain the air temperature and velocity distribution in the cross-sections in the room analyzed. At the end, the validation of the CFD model was undertaken using the results of the temperature from the experimental measurements and the numerical calculations in 21 different points of the room. The maximum difference between those values was around 2°C, which makes a 9.56% error.

Results

The fig. 3 presents the distribution of air temperature and velocity vectors in the cross-section through the supply air diffuser S5 (fig. 1). There is a noticeable area of direct impact of supply air stream characterized by a temperature below 20.5°C and air velocity above $0.15 m\cdot s^{-1}$. The maximum velocity of the supply air is $0.55 m\cdot s^{-1}$, but this value is significantly reduced and at the height of the book shelves it equals $0.25\ m\cdot s^{-1}$. Outside the area of direct impact of supply air stream the temperature is about 21°C and air velocity is less than $0.15\ m\cdot s^{-1}$. Additionally, fig. 3 presents the impact of a person standing next to the rack with an ambient temperature, which results from the heat gains that stem from a human.

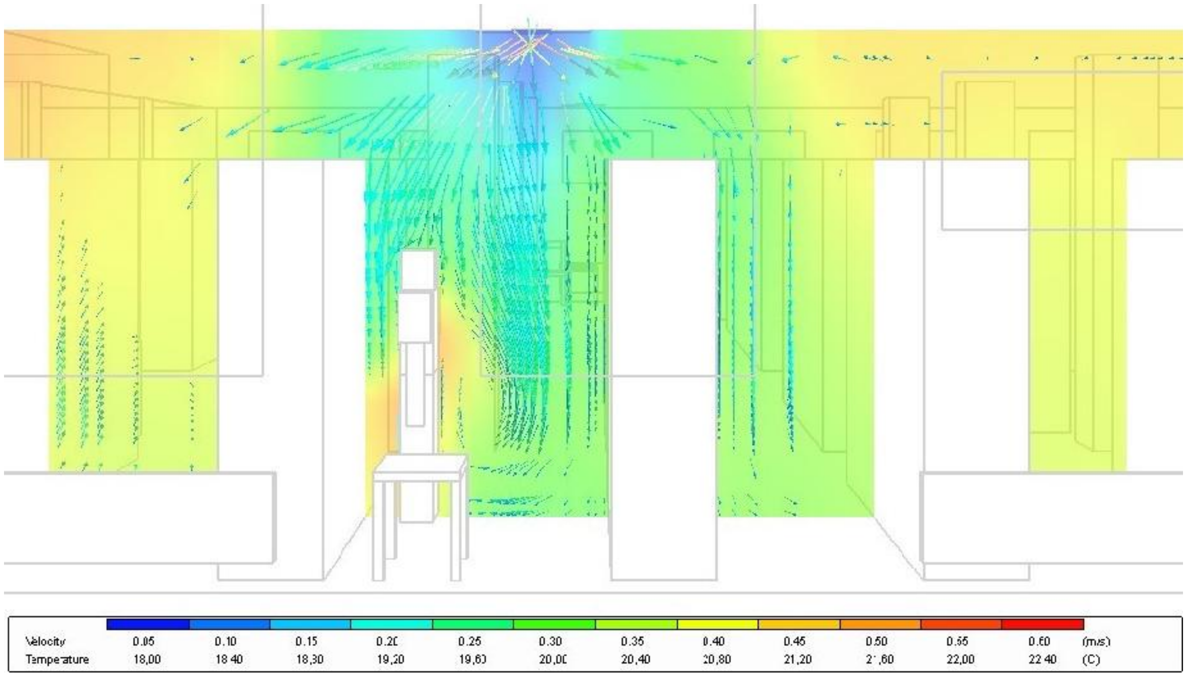

Fig. 3. Distribution of air temperature and velocity vectors in the cross-section through the supply air diffuser S5 (the view from the north side)
Source: Author's

Fig. 4 presents the distribution of air temperature and velocity vectors in the cross-section through the supply air diffuser S1 (fig. 1). There can be distinguished smaller impact of supply air stream on the air parameters near the diffuser than the cross-section from the fig. 3. This results from the lower value of air stream supply to the book room via diffuser S1, which is 29% of the supply air of diffuser S5. The maximum velocity of the supply air is about $0.23 m \cdot s^{-1}$. In addition, fig. 4 shows the air circulation in the areas between the racks with the velocity below $0.12\ m \cdot s^{-1}$. The range of the decreased temperature, which is below 20°C, is less than that for the diffuser S5.

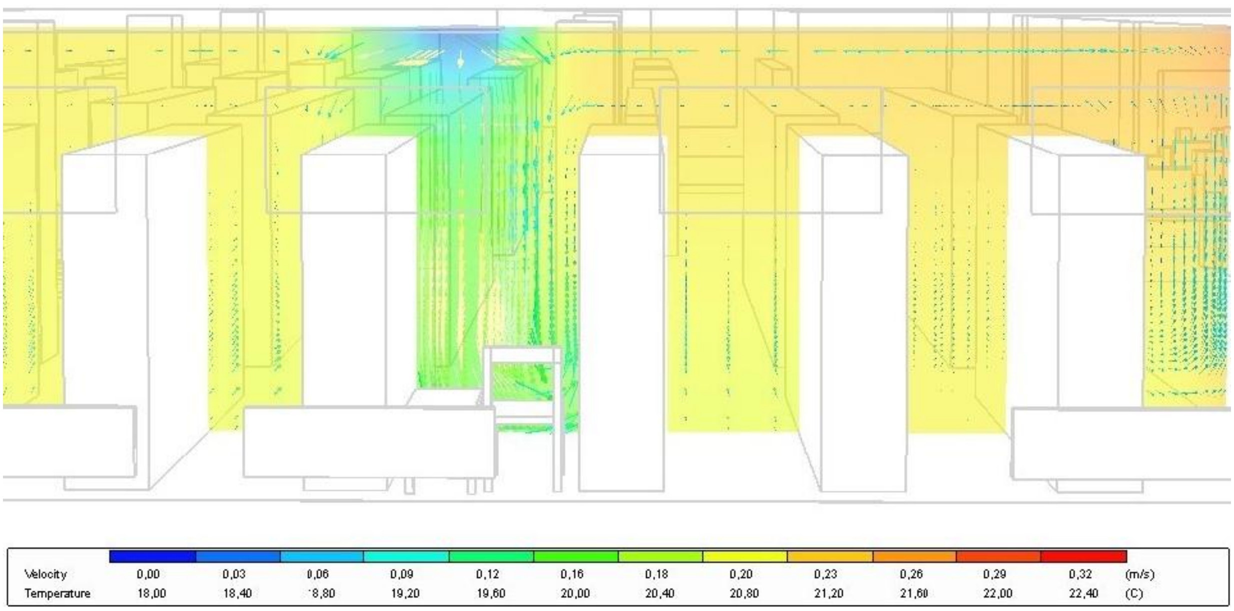

Fig. 4. Distribution of air temperature and velocity vectors in the cross-section through the supply air diffuser S1 (the view from the south side)
Source: Author's

Fig. 5 presents the distribution of air temperature and velocity vectors in the cross-section through the work station of the librarian near the exhaust air diffuser E1 (fig. 1). In this section, the vertical temperature gradient is about 1.2°C, from 20.9°C to 22.1°C. There is also visible convection and increased air temperature near people and computers, which is caused by the additional heat gains. The air flow occurs in the whole cross-sectional area with a velocity that does not exceed 0.16m·s^{-1}. Air movements, presented as velocity vectors directed towards the east, may result from the location of an exhaust air diffuser E1 (fig. 1).

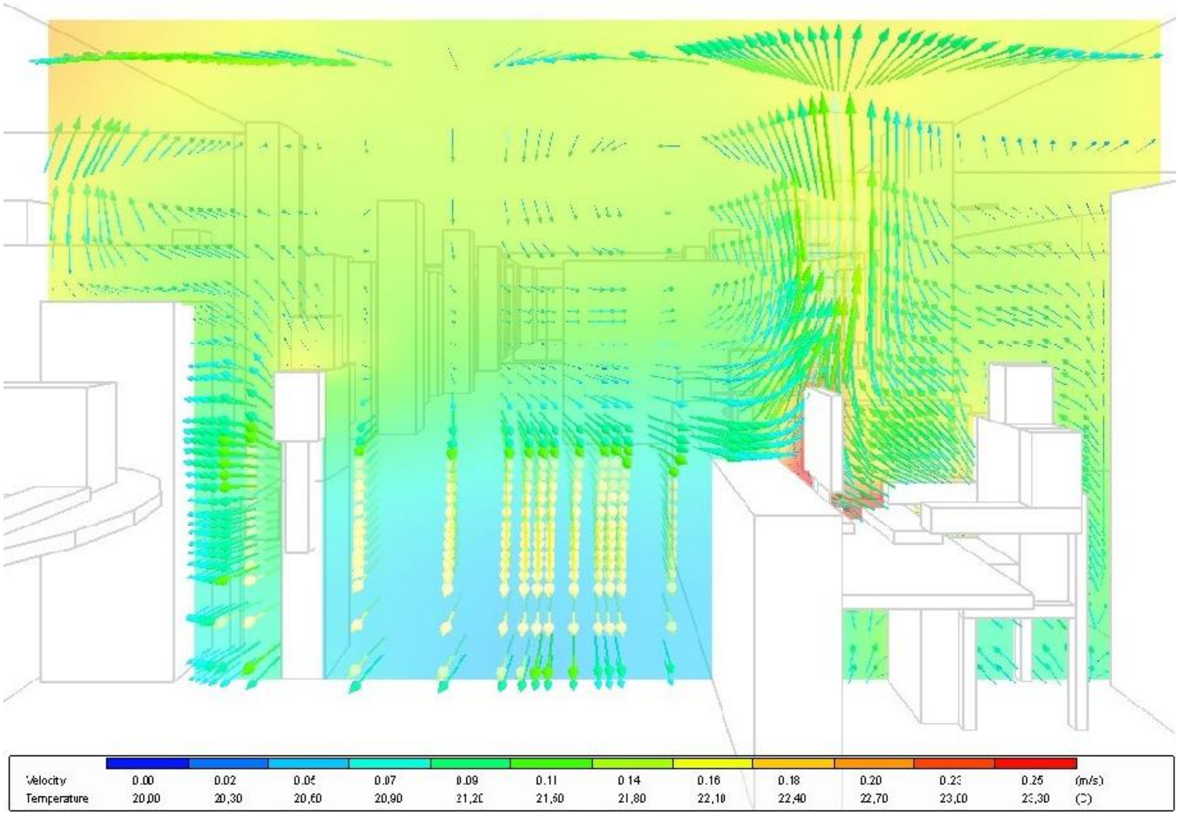

Fig. 5. Distribution of air temperature and velocity vectors in the cross-section through the work station in the vicinity of exhaust air diffuser E1 (the view from the east side)
Source: Author's

Summary and conclusions

The results of the air temperature and velocity numerical calculations in the cross-sections through the book room analyzed were compared with the values recommended for the libraries [1, 10]. The results of the calculations corresponded to the recommended ranges of the temperature (20÷22°C) and velocity (below 0.13 m·s^{-1}). Only in the direct exposure to air diffusers the air temperature was below 20°C and the velocity exceeded 0.13 m·s^{-1}. Moreover, the thermal conditions in the room did not fulfil the requirements of temperature below 18°C recommended for the document storage and mentioned in the PN-EN 11799 standard [1].

Additionally, the values of the air parameters in the cross-section of the room, where people conduct the office work (fig. 5), were compared with the guidance for thermal comfort conditions presented in the PN-EN ISO 7730 standard [10]. This part of the room is designed for the constant presence of people and not for the storage of book resources. Therefore, the priorities for the thermal conditions are the employees' feelings. The temperature gradient did not exceed 2°C, which meets the requirements of category A (table 2) in accordance to the PN-EN ISO 7730 [10] standard. However, the air velocity exceed 0.10 m·s-1, which corresponded to category B [10].

The distribution of air temperature and velocity, obtained using CFD calculations in the DesignBuilder, enabled the analysis of the air parameters in the cross-sections through the book room. The air parameters in the part of the room intended for resources storing partially fulfil the requirements of the air temperature and velocity for the libraries [8]. The recommended ranges were exceeded in the area of the direct impact of supply diffusers. Moreover, the air parameters in the room analyzed did not fulfil the requirements presented in the PN-EN 11799 standard [1] for the document storage. However, the distribution of the velocity vectors indicate a proper air circulation in the space between the racks. Moreover, the air temperature and velocity in the location of the office workstation, partially fulfil the requirements of the PN-EN ISO 7730 standard [10] for the thermal conditions in terms of presence and people's work. The thermal comfort for the personnel was maintained in this part of the room.

There are many publications on the office thermal conditions [17, 24 - 27] and only a several researches on the analysis of the air temperature and velocity related to the thermal comfort in the library rooms [2 - 4]. Although the library seems to have a lot in common with the office rooms, the recommendations of the PN-EN ISO 7730 [10] for an office and of the PN-EN 11799 standard [1] for the library differ significantly. Therefore, it is difficult to design and maintain the appropriate thermal conditions in the room for both the books storage and the thermal comfort of the personnel. The CFD methods can facilitate the conduction of the analysis of the air temperature and velocity as well as the assessment of the thermal comfort conditions in the rooms with a book collection.

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