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Research paper

Indoor air quality in the primary school classroom in Poland – case study

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Abstract: Children spend on average 7–10 hours per weekday at school, that's why the indoor air quality in the classrooms plays a key role in the assessment of the effects of their personal exposure to the air quality. Many scientific articles indicate the substantial influence of carbon dioxide (CO_2) levels and overall air quality within educational environments on the well-being and cognitive performance of children. This article presents the case study of the classroom in the primary school in Cracow with very unfavourable indoor air quality caused by the usage pattern. In the classroom, there is a natural ventilation system, still the most common in the Polish existing buildings. The very high level of CO_2 exceeding the standard requirements connected with low ventilation efficiency effects in harmful indoor conditions. Based on the measurements conducted in the classroom during the lessons with the users in and taking into account formal requirements authors assessed the quality of indoor air. The main reason for those unfavourable conditions is an inefficient natural ventilation system. This paper is also supposed to answer the question of whether temporary opening windows can assure proper concentration of CO_2 in a standard classroom and, if not, what would be the optimal ventilation rate. In the next step, this optimal minimum required ventilation rate for the classroom was calculated. It could be used as a design assumption in the selection of a ventilation system.

Keywords: CO_2, indoor air quality, natural ventilation, school

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1. Introduction

Children spend almost 12% of their life inside classrooms, which is more than in any other building except their homes [1]. That is the reason why the ensuring of high indoor air quality (IAQ) in those particular buildings is so important. IAQ in schools is recognized as one of the most important factors affecting pupil' and students' health and learning outcomes. IAQ in classrooms is mainly assessed by CO_2 levels due to the large amount of users per square meter who exhale contaminated air. Too low oxygen concentration can cause a feeling of breathlessness and headaches, and consequently reduce concentration and the effectiveness of learning. There are many studies in the literature confirming this fact. The review of this research can be found in articles [2–7]. The authors proved that an increased concentration of carbon dioxide negatively affects the absorption of knowledge, therefore, when designing ventilation, special attention should be paid to controlling this concentration. Various groups of students and pupils were subjected to the researches. The results obtained in tests (mathematical, reading comprehension, etc.) with a controlled concentration of carbon dioxide in the range of 600–5000 ppm (depending on the test) were analyzed. All researchers agree that at concentrations above 2000–3000 ppm, the results obtained by students are significantly worse comparing with the results obtained at concentrations below 1000 ppm [2, 6]. The authors [6], on the basis of their own literature review and research, specified the effects of a specific concentration of carbon dioxide:

- 1000 ppm – maximum hygienic,
- 5000 ppm – feeling of fatigue, discomfort,
- 15,000 ppm – breathing disorders,
- 30,000 ppm – dizziness, headaches,
- 50,000 ppm – difficulty breathing, visual disturbances,
- 100,000 ppm – unconsciousness.

Taking into account the research on the correlation of scientific results with the concentration of carbon dioxide and knowing the effects of increased CO_2 concentration, it should be stated that this parameter is very important in educational buildings.

There are many factors affecting the indoor air quality (IAQ) [8], environmental, building related and occupant-related ones. Environmental factors such as climatic conditions and season; building-related factors such as airtightness, schools' location, classrooms and windows' design, type of ventilation, ventilation rate, internal temperature, draughts from windows and room volume. Occupant-related factors such as CO_2 exhalation rate, occupants' behavior, maintenance and operation of systems, operating schedule, number of occupants, activity levels, amount of time spent in the room, occupants' age and individual's thermal comfort.

Healthy IAQ is vital for the health of children as they are more sensitive towards indoor air pollutants. Hence, the effect of occupant-related factors on IAQ is remarkable in the context of primary school buildings, especially considering potential unpredictability of occupant-related factors [8].

Rumor has it that airing by opening windows from time to time (during breaks) is sufficient to ventilate a typically used class served by the natural ventilation system. However, windows cannot be opened when pupils are inside due to draft which causes discomfort and may cause some health problems.

This paper is supposed to answer the question whether temporary opening windows can assure proper concentration of CO_2 in a standard classroom and, if not, what will be the optimal ventilation rate to obtain low CO_2 concentration.

2. Materials and methods

2.1. Internal air quality in schools

Air quality in school buildings is a very significant problem all over the world. The measurements of IAQ parameters such as temperature, humidity, pollutions and CO_2 concentrations are the subjects of analysis of large number of researchers. Godwin [9] described results of IAQ measurements in 64 elementary and middle school classrooms in Michigan (USA). In each classroom, bioaerosols, VOCs, CO_2, relative humidity, and temperature were monitored. Ventilation rates were derived from CO_2 and occupancy data. Ventilation efficiency was poor in many of the tested classrooms, CO_2 concentrations often exceeded 1000 ppm and sometimes 3000 ppm. Grimsrud [1] described results of monitoring of air quality parameters in 85 classrooms and other spaces located in eight schools in Minnesota, US. Carbon dioxide concentrations showed substandard ventilation in rooms in five of the eight schools.

Paraskevi [10] analysed the IAQ in in nine naturally ventilated primary Greek schools in Athens, during spring. The ventilation rates and pollutant levels were analysed and calculated during the teaching and non-teaching periods. The average carbon dioxide (CO_2) concentrations per school varied between 893 and 2082 ppm, while the majority of the cases were slightly above the recommended limit values. CO_2 concentrations were positively correlated to the number of students and negatively correlated to the ventilation rates.

Turanjanin [11] analysed the indoor air quality in five naturally ventilated Serbian schools during the heating season. CO_2 concentrations were measured outdoor and in three classrooms for five working days, ventilation rates were calculated using gas tracing decay method. The results showed the insufficient ventilation and the mean value of carbon dioxide concentration was mostly above 1000 ppm.

Chang [12] conducted similar measurements in five Hong Kong schools where the CO_2 level for most of the time was above 1000 ppm and the maximum level reached 5900 ppm when the classroom was occupied by pupils.

Myhrvold [2] presented the results of the Norwegian project called Indoor Environment in Schools. The aim of the project was to investigate the indoor environment in regard to the pupils' health, social environment and level of performance. Project included field measurements of 8 different schools (35 classrooms) with natural ventilation systems and 800 pupils. The CO_2 concentration at those schools at daytime ranged between 601 and 3827 ppm. The health symptoms such as headache, dizziness, tiredness, difficulties in concentration, unpleasant odour, throat irritation were analysed using questionnaires and analysing the results of computer tests analysing pupils' reaction time. The results showed strong correlation between pupils' health, pupils' performance and CO_2 concentration.

Simoni [3] described the influence of IAQ on respiratory health of schoolchildren living in Norway, Sweden, Denmark, France and Italy. Researchers proved that many disorders such as wheezing, dry cough at night and rhinitis were more prevalent in children from poorly ventilated classrooms. Schoolchildren exposed to CO_2 levels higher than 1,000 ppm showed a significantly higher risk for dry cough and rhinitis. In the analysed schools for 66% of time children were exposed to CO_2 >1,000 ppm. Authors emphasizes the poor IAQ in European classrooms; it is related to respiratory disturbances and affects nasal patency.

Gennaro [4] focused on the analysis of IAQ in schools as children have greater susceptibility to some environmental pollutants than adults, because they breathe higher volumes of air relative to their body weights, and their tissues and organs are actively growing.

Occupant window opening behaviour has a significant impact on both classroom indoor air quality and building energy use. Duton [13, 14] described results of measurements and simulations of indoor air quality conducted in two classrooms in UK including impact of window openings. The simulations were conducted in EnergyPlus program. Author tried to answer the question how to improve the prediction of building performance through improved understanding of occupant behaviour and the factors that influence behaviour. The simulation model was validated by the measurements conducted by authors. The opening of windows improves significantly the air quality, lowers the CO_2 level however due to the external low temperatures or noise outside the building cannot be assumed as the suitable solution of problems.

IAQ is affected by environmental factors temperature, humidity, air contaminants but also but human behaviour, adaptive approach to the thermal comfort and air quality Zhang [15].

Sowa [16] compared real state of environment in classrooms in Poland with accepted requirements and standards based on indoor environment measurements in 28 classrooms in Warsaw. The Polish regulations on indoor air quality drops behind similar regulations in developed countries but what is more important, generally, they are not observed. The increase of ventilation rate would have the key role. Unfortunately this action requires using of mechanical ventilation systems controlling the air change.

Sowa [17–19] described the results of simulations of indoor air quality in the school located in Zgierz after redevelopment of ventilation system from natural one to the mechanical ventilation with high-efficiency heat recovery. After the modernization the ventilation rate increased 10 times in comparison (from 3 m^3/(h pupil) to 30 m^3/(h pupil)).

2.2. Ventilation of internal space

Typical gravitational ventilation system supplies fresh and removes contaminated and humid air directly to and from the internal environment. Too low rate of air exchange can negatively affect the inside air quality and people's health while too high ventilation rate results in excess energy losses. Ventilation, that is intentional air exchange, should be considered in conjunction with infiltration, which is a natural effect of air transfer due to pressure difference between external and internal environment. In case of gravitational ventilation, where usually exhaust ducts only are organized, fresh air supply is provided by the uncontrolled infiltration rate through the cracks and leaks in building external envelope Griffithsa [20]. Airtightness of external building shell is a key factor of ventilation intensity and finally internal air quality

Griffithsa [20] described the influence of trickle ventilators on the ventilation rate on the example of classrooms. They can increase the air flow in the room and reduce the concentration of CO_2 and contaminants but usually do not reduce the concentrations to the acceptable levels.

Lis [21] was trying to answer the question if it is theoretically possible to supply enough air to meet the ventilation requirements with natural ventilation? What is the airtightness of the windows at which it would be possible? The analysis proved that without installing additional vents in the rooms, or better yet, installing mechanical ventilation with heat recovery, meeting the minimum ventilation air flow requirements is not possible.

Mijakowski, Narowski [22] compared the energy performance and indoor climate in typical school classroom with two different ventilation strategies: mechanical balanced ventilation with heat recovery and natural/hybrid ventilation. The primary energy consumption (heating energy and electricity used for ventilation) in rooms with similar ventilation rate and thermal comfort were analyzed. It was showed that providing thermal comfort is not problematic, but energy performance and indoor air quality can vary a lot between different ventilation strategies. In described cases the classroom equipped with mechanical ventilation with heat recovery, for heating and ventilation, consumed about 40% of primary energy less than the one with natural/hybrid solution. Authors proved that in a moderate climate (Europe, Poland) it is possible to meet requirements of indoor climate and keep energy consumption on reasonably level in classrooms with mechanical ventilation with heat recovery as well as in classrooms with natural/hybrid ventilation.

Mijakowski [23] compared the passive stack ventilation performance and indoor conditions before and after installation of humidity-sensitive air inlets in a kindergarten building. The analysis of indoor conditions and ventilation performance showed that although humidity-sensitive air inlets improved performance of ventilation, the effect was not sufficient to meet current Polish and European standards and recommendations.

Measurements of the increase in CO_2 concentration during the use of a building or room allow to determine the quality of indoor air. This approach has been proposed by Persily [25], Bulinska [24], Zhang [26]. The authors confirm that in rooms with natural ventilation, the level of CO_2 very quickly exceeds the legal limits, because the ventilation exchange is usually too low.

2.3. Standard requirements

Polish governmental recommendations do not specify acceptable concentrations of carbon dioxide in rooms intended for permanent residence, only the permissible concentrations in the working environment are defined as follows [27]:

1. Permissible exposure limit (NDS) – the weighted mean value of concentration, the impact on an employee of 8 hours per day and the average weekly working time during his/her working activity should not result in negative changes in his/her health and health of his/her future generations;
2. Short term permissible exposure limit (NDSCh) – mean value of concentration which should not cause negative changes in the worker's health if it is present in the work environment for not more than 15 minutes and not more than 2 times during the work shift, with the a time interval not shorter than 1 hour.

3. Maximum exposure limit (NDSP) – value of concentration which due to health or life threat of the worker, cannot be exceeded in the work environment at any time.

According to this regulation NDS of carbon dioxide is 5000 ppm (9000 mg/m^3), and NDSCh cannot exceed 15 000 ppm (27 000 mg/m^3).

The permissible levels of carbon dioxide are defined in the European standards and commonly used US requirements ANSI/ASHRAE [28] and ASTM [29]. According to those requirements the upper level of carbon dioxide concentration in spaces for permanent residence of people should not exceed 1000 ppm. To keep this requirement ca. 27 m^3/h of fresh air per person should be supplied per hour [28].

According to the PN-B-03430 standard [30], which has been commonly used for years in designing the size of the ventilation flux, in public utility buildings intended for permanent and temporary stay of people, the required external air volume flow should be at least 20 m^3/h per person. However, in the case of rooms in kindergartens and nurseries where children stay, the standard allows for a reduction of the air volume flow to 15 m^3/h for each child. It should be noted that these rooms are also occupied by adults caring for children, for whom the stream should be calculated as 20 m^3/h per person.

An overview of the requirements applied in other countries can also be found in the study by Ludwiczak [5]. Detailed guidelines adapted to the age of users of educational buildings are included, among others, in the American ASHRAE 61.1 [28] guidelines. There, a detailed information on the required outside air flow can be found. The designed stream is the sum of the stream per one person staying in the room and associated with human activity and the stream associated with building materials and room equipment, calculated depending on its area. The guidelines for educational rooms are presented below:

– nursery rooms (for children up to 4 years old) – 18 m^3/h per person,
– classes (for children aged 5–8) – 18 m^3/h per person,
– classes (for children from 9 years of age) – 18 m^3/h per person,
– lecture rooms – 13.4 m^3/h per person,

Permissible levels of carbon dioxide in non-residential spaces are regulated by the standard EN 16798-1 [31]. It introduces four acceptable levels of carbon dioxide concentration depending on the selected level of indoor air quality. The Table 1 shows the permissible values of the carbon dioxide concentration according to the air quality category.

Table 1. Permissible values for carbon dioxide concentration to the air quality category, acc. to standard EN 16798-1 [31]

Category of air quality in the room	**Increment of CO_2 concentration above CO_2 level in external air, [ppm]**
High quality of air	350
Medium quality of air	500
Moderate quality of air	800
Low quality of air	1200

In every enclosed space where a human resides, the concentration of carbon dioxide increases because of depletion of the oxygen due to process of breathing. The carbon dioxide concentration in exhaled air is about 40 000 ppm [29]. However, the exact amount of CO_2 produced by human body may differ depending on its weight and level of metabolic activity [28, 29].

The European standard EN-16798-1 [31] assumes that the indicative CO_2 emission is equal to 20 l/h per person. This value will be taken as a standard in further calculations.

2.4. Tested classroom

The analysed classroom is located on the ground floor of the two-storey primary school building located on Mackiewicza Street in Cracow about two kilometres from the old city centre Fig. 1, Fig. 2. Room can be used by maximum of 31 people (30 pupils plus teacher). The room has only one external wall with three large (2.55 m width and 1.8 m height) windows at west elevation of building. In the room there is natural ventilation system with four ventilation ducts 10 cm by 10 cm located 3.0 m above floor level.

Total floor area of the classroom is equal to 51.92 m^2 and its internal volume is 166.14 m^3.

Fig. 1. East elevation of analysed school building

Fig. 2. Internal view of classroom

All the measurements were conducted using set of remote sensors iBros allowing the continuous measurements and registration of CO_2 concentration, temperature and relative humidity (Fig. 3). Recordings were taken every 30 seconds. CO_2 measurement precision was ±50 ppm, temperature ±0.4°C, relative humidity ±5%.

Fig. 3. iBros remote sensors set measuring CO_2

The simultaneous measurements of CO_2, temperature and humidity have been conducted using nine detectors. The detectors were located in different places of the tested space, which allows for the evaluation of spatial distribution of CO_2, temperature and fluctuations of the momentary concentration within the internal space. Description of sensors' locations was presented in Table 2. Before performing the test all the sensors were calibrated in accordance with the manufacturer's instruction.

Table 2. Description of the sensors' locations

Sensor number	Sensor location
#1	Located on the window sill or outside on the window sill
#2	Located on the window sill or outside on the window sill
#3	Attached to the entrance door frame, 2.0 m above floor.
#4	Located on the desk next to the wall, opposite the windows.
#5	Located on the desk next to the wall, opposite the windows.
#6	Located on the wardrobe, 1.8 m above floor, next to the ventilation ducts
#7	Located on the wardrobe, 1.8 m above floor,
#8	Located on the internal window sill
#9	Located on the projector 20 cm below the soffit

Measurements of internal air quality were carried out for 3 days 04.01.2019, 11.01.2019 and 01.02.2019 in the morning hours during the classes.

The detailed analysis were based on one representative day (04.01.2019) to emphasize the observed phenomena. The trends in the CO_2 and temperature distributions in all days were similar. The outdoor CO_2 concentration on the chosen day averaged 557 ppm.

Figure 4 presents variability of air temperature in the classroom on 4th of January. There are significant differences between values due to the location of sensors. Sensors #2 and #8 are located on the window sills inside the class. The temperature at both are the lowest due to the leaks of cold air from outside. During the second break at 10:40 sensor #2 was moved on the external sill. The significant drop can be noticed and the readings after that shows external temperature conditions. The drops on all sensors can be observed during breaks when the windows were opened. The highest values are recorded on the sensor located next to the ceiling on the projector. The temperature there is the highest due to the convection of warm air.

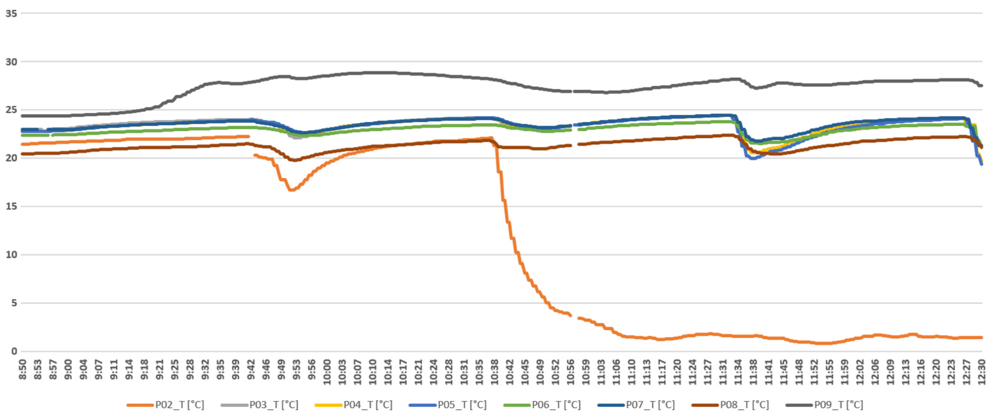

Fig. 4. Temperature distribution at all sensors on 4^{th} of January

Figure 5 shows the trend for rising and fall of CO_2 levels during school occupancy in the classroom on 4th of January. Number of users – 21 pupils plus two adults. Figures 4 and 5 present the shorter time range, two lessons with the break between lessons when the windows were opened. Fig. 6 based on data taken on 11th of January, Fig. 7 average data from 6 sensors taken on 1st of February.

The lessons starts at 8:55, children get into the classroom around 8:40–08:50. Each lesson is 45 minutes long. The first lesson ends at 9:40 and children leave for a short 10 minutes break (9:40–9:50 a.m.). According to Fig. 3, mean CO_2 concentration goes up to 2500 ppm until the first break and reduces to 1250 ppm during the first break (50% reduction) due to the opened windows. The reduction of 1250 ppm during 10 minutes break gives 125 ppm/min among studied classroom. Breaks are not long enough to decrease CO_2 levels below 1000 ppm. After the first break, children remain in the classroom until next 10 minutes break (9:50–10:35). The upper value of CO_2 concentration at the second lesson is even higher 3000 ppm as the initial value was higher. The same trend repeats during next two lessons. This trend for rising and fall of CO_2 levels in studied schools is described in many other studies [8, 16].

Figures 4, 5 show that breaks between the lessons can lower the level of CO_2 concentration however they are not long enough to exchange the air inside the classroom or to at least lower the level to less than 1000 ppm.

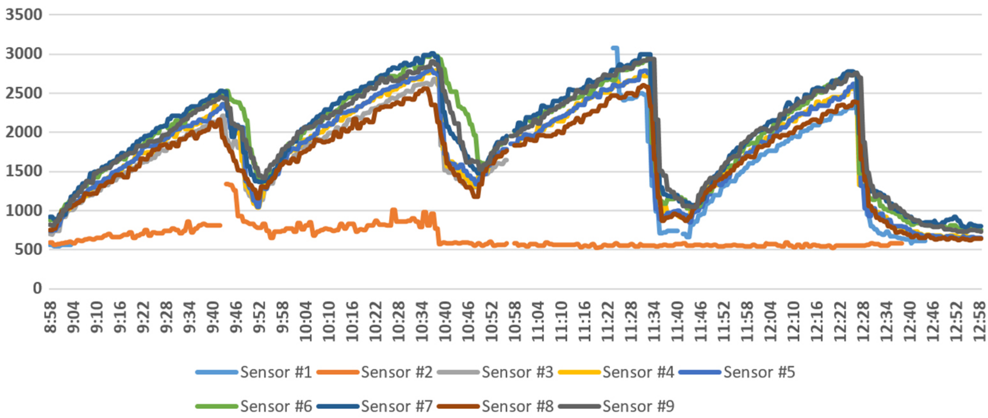

Fig. 5. CO_2 concentration in the classroom on 04^{th} January 2021

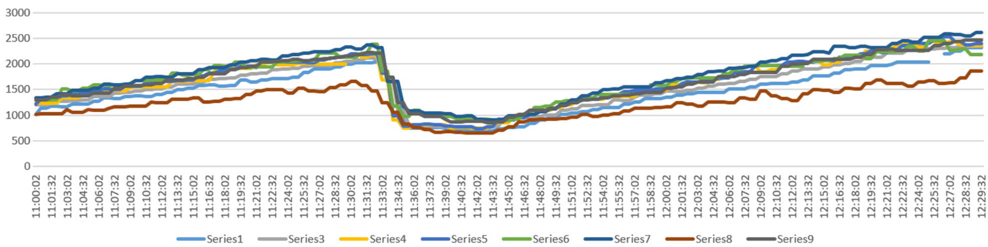

Fig. 6. CO_2 concentration in the classroom on 11^{th} of January 2021 between 11:00 am and 12:30 am; two 45 minutes lessons with the break at 11:30–11:45 – windows opened

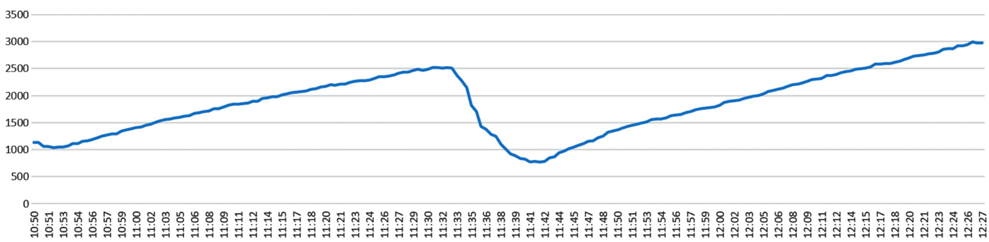

Fig. 7. CO_2 average concentration from 6 sensors – 1^{st} of February 2021

The windows are closed during teaching period due to low exterior temperatures or outdoor noise. This is typical usage scheme in the classrooms in Poland but also in different countries and was described in [8, 16].

The levels of CO_2 at different sensors differ and the values are affected by the location of sensors and usage pattern of the classroom. In general, the higher momentary concentration values are observed at the sensors located closer to the users' heads, i.e. CO_2 emission sources.

Sensor #8 was located on the internal window sill, next to the window. Due to its uptightness the values are the lowest. The highest values can be observed of the sensor located below the soffit (sensor #9) and at the one located on the back of the classroom, on the wardrobe next to the ventilation ducts (sensor #6 and #7) (Fig. 5). Regarding sensor #9, below the soffit it can be explained by the convection of warm air which moves the CO_2 particles to the top of room. Also the temperatures during the analyzed period on this specific sensor are much higher (Fig. 4).

The higher values of CO_2 next to the ventilation duct (sensors #6 and #7) indicate the direction of air flow in the classroom, the CO_2 particles move to the exhaust ventilation duct.

Based on the collected data the quality of internal air was classified. The external concentration of CO_2 during entire measurement time was assumed at the level of 400 ppm. The levels of internal concentration of carbon dioxide in the analyzed period of time were described in Table 3. Percentage share of concentration levels was based on the averaged values from seven sensors. The comfort value of 1000 ppm [29] concentration is exceeded for **98%** of occupation time. Per the classification of standard [30] that was presented in Table 1, the indoor air quality in the classroom for **73.5%** of analyzed time can be qualified as low (the worst defined in this standard category), which is very unsatisfactory result. Graphic interpretation of table is shown in (Fig. 8).

Table 3. Total concentration of CO_2 in the classroom on 4th of January between 9:00 and 12:30

	<1000 ppm	**>1000 ppm**	**>1600 ppm**	**>2000ppm**
Percentage of readings	1.9%	24.6%	22.5%	51.0%

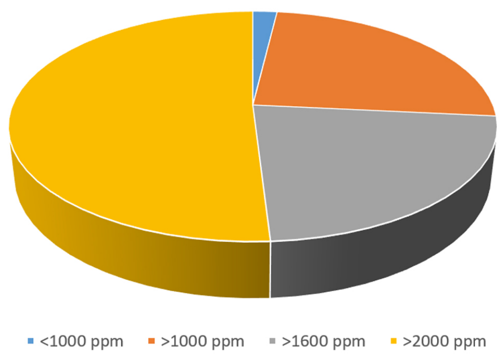

Fig. 8. Percentage of readings with different levels of concentration

The high concentration of CO_2 found in the above tests results from the insufficient ventilation efficiency. In the next steps, attempts were made to determine the intensity of ventilation in the classroom.

2.5. Improvement of ventilation in the tested classroom

One of the ways to improve the dilution process of CO_2 is to use the mechanical ventilation system. There are several types of the systems but to solve the entire problem the first step should be to determine the required airflow. The outside air flow [m^3/s] should be determined using the equation:

$$Q_h = \frac{G_h}{C_{h,i} - C_{h,o}} \cdot \frac{1}{\varepsilon_v} \tag{2.1}$$

where: G_h – flow of contaminating gas [mg/s], ε_v – ventilation efficiency, $C_{h,i}$– allowable concentration of the pollutants in the air [mg/m^3], $C_{h,o}$ – concentration of the pollutants in the supply air [mg/m^3].

The flow of contaminating gas was derived from the measurements and estimated as: 179.4 mg/s.

The flow seems to be large but first – it has been calculated from the average values measured in-situ, second they take into consideration the entire classroom filled with 25 kids and two adults (teacher and researcher).Ventilation efficiency depends mostly on the airflow pattern created by supply and exhaust air terminal devices as well as temperature difference between room air and supply air. For the sack of the simplicity the efficiency is set to 1.

Keeping allowable concentration at 1000 ppm (1830 mg/m^3) and outside 400 ppm (723 mg/m^3), the maximum airflow calculated from the above Equation (2.1) is: 584 m^3/h. Assuming optimal placement of supply and exhaust air terminal the required airflow to dilute CO_2 to the level of 1000 ppm the system will create the change rate at the value of 3.5 1/h.

Now it is the time to discuss the possible solutions of mechanical ventilation. One can choose from exhaust-only, supply-only, balanced and balanced with the heat recovery together with CO_2 level control system. The choice will determine the investment and operational cost of the system.

3. Conclusions

Analysis of indoor air quality in schools is very important as children spend on average 7-10 per weekday at school. The example described in this article shows very unfavorable conditions in the analyzed classroom. Due to the large number of users in the classroom the level of metabolically generated CO_2 increases rapidly. The low efficiency of natural ventilation system leads to the exceedance of standards and reaches the levels which could be harmful for users.

The opening of windows during the breaks between the lessons can lower the level of CO_2 concentration however they are not long enough to exchange the air inside the classroom or to at least lower the level to less than 1000 ppm. During the lessons windows must be closed due to low exterior temperatures or outdoor noise. This is typical usage scheme in the classrooms in Poland.

In such conditions the usage of mechanical ventilation would be necessary. Based on the data from measurements authors calculated the min air change rate at the level of 3.5 changes per hour. This result could be reached using different mechanical ventilation systems, such as exhaust-only, supply-only, balanced or balanced with the heat recovery together with CO_2 level control system. The choice will determine the investment and operational cost of the system. The deeper analyses of possible solutions will be the subject of the next analyses and simulations planned by the authors.

References

[1] D. Grimsrud, B. Bridges, and R. Schulte, "Continuous measurements of air quality parameters in schools", *Building Research and Information,* vol. 34, no. 5, pp. 447–458, 2006, doi: 10.1080/09613210600808880.

[2] A. Myhrvold, E. Olsen, and O. Lauridsen, "Indoor environment in schools – pupils health and performance in regard to CO2 concentrations", presented at Indoor Air 1996.

[3] M. Simoni, I. Annesi-Maesano, T. Sigsgaard, et al., "School air quality related to dry cough, rhinitis and nasal patency in children", *European Respiratory Journal*, vol. 35, no. 4, pp. 742–749, 2010, doi: 10.1183/09031936.00016309.

[4] G. Gennaro, P. Dambruoso, A. Demarinis Loiotile, et al., "Indoor air quality in schools", *Environmental Chemistry Letters*, vol. 12, pp. 467–482, 2014, doi: 10.1007/s10311-014-0470-6.

[5] A. Ludwiczak and K. Ratajczak, "Ventilation of didactic and educational facilities – a review of selected Polish and foreign requirements for air flow and carbon dioxide concentration", *Rynek Instalacyjny*, no. 3, 2018.

[6] A. Murkowski and E. Skórska, „Czy zwiększona zawartość dwutlenku węgla w powietrzu ma wpływ na sprawność intelektualną człowieka?", *Kosmos – Problemy Nauk Biologicznych*, vol. 65, no. 4, pp. 631–636, 2016.

[7] A. Cohen, A. Anderson, B. Ostro, et al., "The global burden of desease due the outdoor air pollution", *Journal of Toxicology and Environmental Health, Part A,* vol. 68, no. 13-14, pp. 1301–1307, 2005, doi: 10.1080/15287390590936166.

[8] S. Korsavi, A. Montazami, and D. Mumovic, "Indoor air quality (IAQ) in naturally-ventilated primary schools in the UK: Occupant-related factors", *Building and Environment*, vol. 180, 2020, doi: 10.1016/j.buildenv.2020.106992.

[9] C. Godwin and S. Batterman, "Indoor air quality in Michigan schools", *Indoor Air*; vol. 17, pp. 109–121, 2007, doi: 10.1111/j.1600-0668.2006.00459.x.

[10] P. Dorizas, M. Assimakopoulos, C. Helmis, and M. Santamouris, "An integrated evaluation study of the ventilation rate, the exposure and the indoor air quality in naturally ventilated classrooms in the Mediterranean region during spring", *Science of The Total Environment*, vol. 502, pp. 557–570, 2015, doi: 10.1016/j.scitotenv.2014.09.060.

[11] V. Turanjanin, B. Vučićević, M. Jovanović, N. Mirkov, and I. Lazović, "Indoor CO2 measurements in Serbian schools and ventilation rate calculation", *Energy*, vol. 77, pp. 290–296, 2014, doi: 10.1016/j.energy.2014.10.028.

[12] S.C. Lee and M. Chang, "Indoor and outdoor air quality investigation at schools in Hong Kong", *Chemosphere,* vol. 41, no. 1–2, pp. 109–113, 2000, doi: 10.1016/s0045-6535(99)00396-3.

[13] S. Dutton and L. Shao, "Window opening behavior in a naturally ventilated school", presented at Fourth National Conference of IBPSA-USA, New York, 2010.

[14] S. Dutton, "Window opening behavior and its impact on building simulation: a study in the context of school design", PhD thesis, University of Nottingham, UK, 2009.

[15] H. Zhang, C. Huizenga, E. Arens, and P. Lyons, "Window Performance for Human Thermal Comfort", Report to National Fenestration Rating Council, November 2005.

[16] J. Sowa, "Air quality and ventilation rates in schools in Poland – requirements, reality and possible improvements", presented at Indoor Air 2002.

[17] J. Sowa, "Air quality and ventilation rates in schools in Poland – requirements vs. reality", in *Proceedings 21st AIVC Annual Conference "Innovations in Ventilation Technology", 26-29 September 2000*, paper 53, 2000.

[18] J. Sowa, B.J. Wachenfeldt, A. Panek, and O. Aschehoug, "Analysis of Technologies for Improving Indoor Air Quality During Sustainable Redevelopment of Polish Schools", Conference Paper, 2006.

[19] J. Sowa and A. Karas, "Whole year simulation of natural and hybrid ventilation performance and estimation indoor air quality for modernized school building", presented at Clima 2007, WellBeing Indoors.

[20] M. Griffiths and M. Eftekhari, "Control of CO_2 in a naturally ventilated classroom", *Energy and Buildings*, vol. 40, no. 4, pp. 556–560, 2008, doi: 10.1016/j.enbuild.2007.04.013.

[21] P. Lis and A. Lis, "Required amount of ventilation air in the classroom and the possibility of air entering through windows", *Energies*, vol. 14, no. 22, 2021, doi: 10.3390/en14227537.

[22] M. Mijakowski and P. Narowski, "Indoor Climate and Energy Standard of School Buildings with Different Ventilation Strategy", in *CLIMA 2016 - Proceedings of the 12th REHVA World Congress*. Aalborg University, 2016.

[23] M. Mijakowski and J. Sowa, "An attempt to improve indoor environment by installing humidity sensitive air inlets in a naturally ventilated kindergarten building", *Building and Environment*, vol. 111, pp. 180–191, 2017, doi: 10.1016/j.buildenv.2016.11.013.

[24] A. Bulińska, "Analysis of the use of metabolically generated carbon dioxide as a tracing gas for determination of indoor air exchange" PhD thesis, Gliwice, 2011 (in Polish).

[25] A.K. Persily, "Evaluating Building IAQ and ventilation with indoor carbon dioxide", *Ashrae Transactions*, vol. 103, pp. 1–12, 1997.

[26] W. Zhang, L. Wang, Z. Ji, L. Ma, and Y. Hui, "Test on ventilation Rates of Dormitories and Offices in University by the CO_2 Tracer Gas Method", *Procedia Engineering*, vol. 121, pp. 662–666, 2015, doi: 10.1016/j.proeng.2015.08.1061.

[27] Regulation of the Ministry of Labor and Social Policy of November 29, 2002 regarding the highest allowable concentrations and factors harmful to health in the working environment (in Polish).

[28] ANSI/ASHRAE Standard 62.1-2019. Ventilation for acceptable indoor air quality. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 2019.

[29] ASTM Standard D 6245-98. Standard guide for using indoor carbon dioxide concentrations to evaluate indoor air quality and ventilation. American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1998.

[30] PN-83/B-03430 Wentylacja w budynkach mieszkalnych, zamieszkania zbiorowego i użyteczności publicznej. Wymagania. Polski Komitet Normalizacyjny, 1983.

[31] EN 16798-1: 2017 Ventilation for non-residential buildings - Performance requirements for ventilation and room-conditioning systems. 2017.

[32] G. Walton and W. Stuart Dols, *CONTAM User Guide and Program Documentation*. National Institute of Standards and Technology, 2010.

[33] N. Szczepanik-Ścisło and A. Flaga-Maryańczyk, "Measurements and simulation of CO2 concentration in a bedroom of a passive house", *Technical Transactions. Environmental Engineering,* vol. 115, no. 9, pp. 163–179, 2018, doi: 10.4467/2353737XCT.18.139.8978.

Jakość powietrza wewnętrznego w sali lekcyjnej szkoły podstawowej w Polsce – studium przypadku

Słowa kluczowe: CO_2, jakość powietrza, szkoła, wentylacja naturalna

Streszczenie:

Dzieci spędzają w szkole średnio 7–10 godzin dziennie, dlatego jakość powietrza w klasach odgrywa kluczową rolę w ocenie ewentualnych skutków ich narażenia na złą jakość powietrza. Wiele artykułów naukowych wskazuje na istotny wpływ poziomu dwutlenku węgla i ogólnej jakości powietrza w środowiskach edukacyjnych na samopoczucie i zdolności poznawcze dzieci. W artykule przedstawiono studium przypadku, analizę sali lekcyjnej szkoły podstawowej w Krakowie, w której panowała bardzo niekorzystna jakość powietrza wewnętrznego spowodowana sposobem użytkowania. W klasie zastosowano system wentylacji naturalnej, wciąż najczęściej spotykany w istniejących polskich budynkach.

Na podstawie pomiarów przeprowadzonych w sali lekcyjnej podczas zajęć z użytkownikami oraz biorąc pod uwagę wymogi formalne, autorzy ocenili jakość powietrza w pomieszczeniu. Główną przyczyną tych niesprzyjających warunków jest nieefektywny system wentylacji naturalnej. Artykuł ma także odpowiedzieć na pytanie, czy tymczasowe otwieranie okien może zapewnić odpowiednie stężenie CO_2 w typowej sali, a jeśli nie, jaki byłby optymalny strumień wentylacji dla zapewnienia wymaganiej przepisami jakości powietrza. Obliczony strumień może zostać wykorzystany jako założenie projektowe przy doborze systemu wentylacyjnego.

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Research paper

Factors influencing labour safety within construction sites in the Mekong delta

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Abstract: Construction workers consistently prioritise safety when carrying out their tasks on construction sites. The matter of ensuring labour safety on construction sites requires attention, investment, and strict adherence to regulations from the outset. This is crucial due to the numerous potential risks inherent in the construction industry. In the current market economy, many entities have shown a lack of focus on safety in favour of profit. This article examines the factors influencing labour safety during the construction process on sites in the Mekong Delta region. It employs a survey to gather insights from experts and managers in the area, followed by the application of SPSS software to quantitatively assess the impact of these factors on labour safety in the region's construction sites. The analysis results provide a foundation for relevant units to suggest solutions aimed at minimising occupational accidents and enhancing awareness among participants at construction sites across the country, with a specific focus on the Mekong Delta region. This initiative ultimately aims to ensure that workers at construction sites enjoy a comfortable and safe working environment, while also mitigating financial losses to the national budget and fostering a secure workplace for all workers.

Keywords: construction site, accident, labour safety, project, risk

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1. Introduction

Research [1] indicates that this industry has consistently been recognised as one of the most hazardous and perilous sectors, characterised by elevated accident and fatality rates. Farooqui et al. [2] highlight that the mortality rate in the construction sector is notably higher than in other sectors. In Hong Kong, the construction industry has a death rate of 64.2‰, whereas other industries have a significantly lower rate of 8.6‰. In Canada, the overall death rate across all industries is 6.1‰, whereas in construction, it rises significantly to 20.9‰.

Numerous studies exist in this area, including research [3–6], which focusses on construction safety management as a means of regulating safety policies, procedures, and practices on construction sites. The process is dynamic and can be tailored to the activities at the construction site, ensuring that the desired goals are met while preventing occupational accidents during regular operations on the site [7].

Ning et al. [8] examined the elements influencing safety management in construction projects within China. The research highlighted six elements that influence construction safety management: safety training, promotion of safety policies, elimination of safety hazards, safety supervision, management's commitment to safety, and the safety budget. Jokkaw and Tongthong [9] examined the factors influencing safety management status and assessed the safety management status in construction projects in Cambodia. The study identified nine factors that are deemed to have a significant impact on safety management in construction sites, including: budget allocated for safety management, safety policy, project manager awareness, safety training, safety organisation, safety regulations, use of personal protective equipment (PPE), investigation of accidents on construction sites, and establishment of safety committees. Yadi et al. [10] examined the key factors contributing to the effectiveness of occupational safety (OSH) management in high-rise construction projects in China. Six groups of key success factors were identified: management measures, management organisation, management plan, OSH behaviour, safety environment, and workers' safety knowledge and awareness.

Many other researchers, including Priyadarshani et al. [11, 12], have also reported similar studies. The findings of the research review indicate that the topic of occupational safety in construction has garnered significant interest from numerous researchers. In Vietnam, there has not been a dedicated study examining the factors influencing and the metrics for assessing occupational safety management in construction sites. This study has identified 21 factors that influence occupational safety management on construction sites, based on a review of previous studies. These factors serve as the foundation for constructing and developing the survey in this research.

Research [13] indicates that the factors associated with project complexity are consistently referenced in all studies pertaining to construction management, as they can influence a majority of project management activities. This includes elements such as the intricacy of the structure and architecture. Additionally, studies [14, 15] have explored factors related to pressure on progress. The two studies indicate that a significant factor contributing to occupational safety loss is the pressure to prioritise project progress for timely use, which often results in extended work shifts or the concentration of numerous construction resources.

Research has identified a range of factors associated with errors in construction drawing design [14, 16]. These studies highlight issues related to the construction process or sequence depicted in the design, which can result in mistakes during workers' operations and may lead to occupational safety risks. Studies [17, 18] indicated that training and education on occupational safety for each working group influence occupational safety. Research on factors related to leadership capacity highlighted the importance of communication from management positions during project implementation regarding operational activities to subordinates [15, 18]. The study examined the influence of occupational accidents on the performance of workers on construction sites and the overall team dynamics [19]. The study found that the Board of Directors of construction companies in the industry ought to place a higher importance on the health and safety of workers rather than on economic concerns associated with training expenses. The research primarily focused on occupational health and safety concerns within construction sites in the Czech Republic [20].

A study in Vietnam [21] examines the impact of various factors associated with the contractor's construction organisation process on construction safety in construction projects within the country. The research findings have consolidated the primary categories of factors and highlighted that the groups associated with safety training and coaching, the contractor's safety assurance capabilities, and the competencies of project leadership roles exhibit a statistically significant impact ($p \ll 0.05$) on construction safety. However, the study has not put forth any solutions to mitigate occupational accidents on construction sites. The study [22] aimed to evaluate how worker characteristics and management methods influence worker safety performance. The study utilised multiple regression analysis and statistical tests to identify 9 worker characteristics and 8 management factors that impact workers' safety performance. Furthermore, the rate of accidents was assessed by evaluating the time lost during incidents, with an average of 0.193‰ recorded.

Study [23] Construction sites present challenging working conditions with numerous potential hazards for accidents. To ensure labour safety, it is essential for workers and engineers to wear protective equipment, particularly safety helmets, upon entering the construction site. Nonetheless, unfortunate incidents continue to happen. A primary reason is that the safety helmets utilised by workers do not effectively assist in preventing labour accidents. Study [24] This research establishes a framework for evaluating occupational safety management (OSM) at construction sites in Ho Chi Minh City. The research has pinpointed 16 elements that influence OSM management in construction environments.

Tung [25] examined the key factors influencing the execution of the occupational safety program in construction projects in Vietnam. The research findings indicated that the periodic assessment of the safety program's effectiveness was the most significant factor. Through factor analysis, eight factors were consolidated into four primary factors: Oversight and assessment of safety measures at the construction site; Execution and regular review of the safety program; Adequate resources paired with education and training; Effective collaboration among all participants at the construction site. Phuong [26] carried out a study that integrated the EFQM model with system dynamics to enhance safety culture. The author outlined six primary categories of factors that influence the safety culture within the organisation: (1) Leadership, (2) Policy and strategy, (3) People, (4) Partnerships and resources, (5) Process, (6) Goals.

Duc [27] examined the elements influencing labour safety costs and introduced a quantitative forecasting model for these costs in construction projects in Ho Chi Minh City. The results identified various factors influencing labour safety costs, including those associated with accident barriers and security at the construction site, construction measures, transportation of materials to elevated areas, the structure of the construction site, inspection of safety measures during equipment operation, the frame of the net covering around the site, pile foundation equipment, worker health, protective gear for individuals entering the site.

In this paper, based on the review of both international and domestic research, it is essential to examine the effects of construction on labour safety at construction sites in the Mekong Delta region. This will enable the proposal of suitable solutions aimed at enhancing labour safety and reducing labour accidents for construction workers.

2. Materials and methods

2.1. Research Procedure

Secondary data collection methods: Secondary data refers to the information that the author has gathered and synthesised from various research projects, both domestically and internationally. This method assists the author in gathering essential information during the report writing process.

Primary data collection methods: The expert method involves gathering insights from specialists to assess and evaluate a product, event, or practical issue. The expert method gathers diverse viewpoints from specialists, allowing them to evaluate one another for a more impartial understanding of a given issue. The investigation and survey method is recognised as a sociological approach and is frequently utilised across various disciplines. The questionnaire investigation method involves three key areas that require careful consideration: sample selection, questionnaire design (interview form), and result processing [28]. Develop and create interview questionnaires using clear, straightforward language, minimising abbreviations and ambiguous terms; avoid referencing private or sensitive personal matters. In the study assessing factors influencing labour safety at construction sites in the Mekong Delta region, the author employed a 5-level Likert scale to gather feedback from participants (shown in Figure 1).

2.2. Data collection method

The survey consists of three sections:

- Part 1: in project implementation, and types of projects they have participated in, along with information about the individuals involved in the interview.
- Part 2: A comprehensive evaluation of the effects of construction on labour safety at construction sites in the Mekong Delta.
- Part 3: Evaluation of the effects of construction on worker safety in the Mekong Delta.

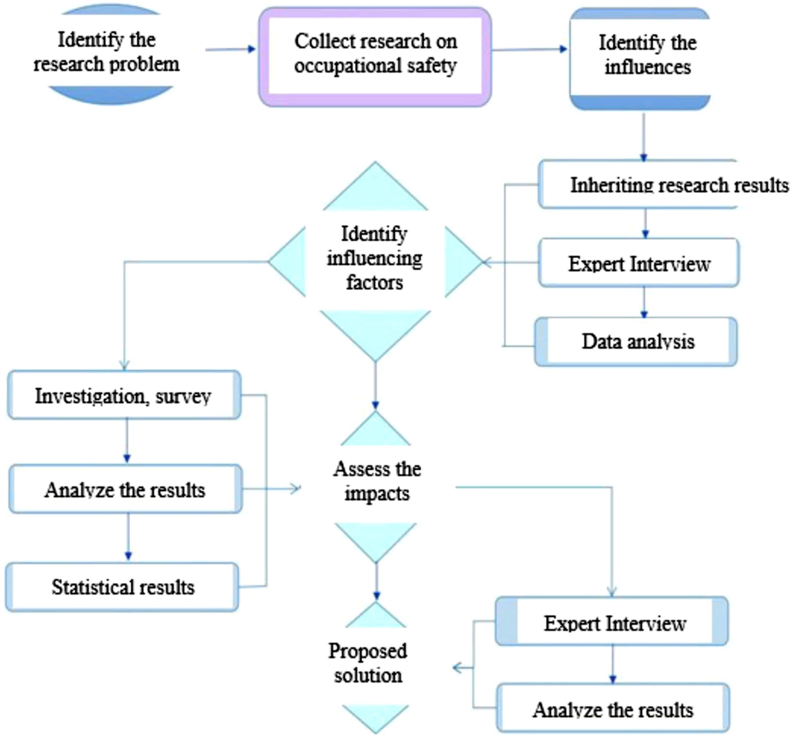

Fig. 1. Research diagram [Authors]

2.3. Data analysis and processing methods

For qualitative data in-depth interviews: Following comprehensive interviews with experts aligned with the research objectives regarding the influence of construction on labour safety at construction sites in the Mekong Delta, the author compiled the responses of the research subjects documented in the diary. Subsequently, the author chose significant, persuasive, and credible content that aligns with the research objectives of the topic to incorporate into the report. The study ultimately examined the data by creating an interview analysis table, choosing keywords and associated information to enhance the credibility of the report.

For quantitative data:

– The research team utilised specialised software SPSS 20 to clean and process the data, aiming to identify the trends and statistical patterns within the collected data set.
– The author employs exploratory factor analysis (EFA) to identify the factors influencing labour safety in construction sites within the Mekong Delta region. The study employed a 5-level influence scale to assess the information [29].
– The distance value is calculated as (maximum–minimum)/n, which equals (5 – 1)/5, resulting in 0.8. Where: Max represents the highest value, Min denotes the lowest value, and n indicates the scale utilised (Table 1).

Table 1. Analysis of the average values [29]

Scale	1	2	3	4	5
	No effect	Little Affect	Affect	Significant effect	Extremely effect
Value	1.00–1.80	1.81–2.60	2.61–3.40	3.41–4.20	4.21–5.00

Exploratory factor analysis The process of EFA involves the subsequent steps:

- Step 1: Conduct the Cronbach's Alpha test [29–32].
- Step 2: Exploratory Factor Analysis (EFA) [29–32].
- Step Three: Analysis of the factor score matrix: Employ the factor score matrix analysis technique to identify the variables that exert significant or minimal influence on each factor within the model.

Utilise the analysis results from objective 1 and objective 2 to assess, from which proposed solutions can be derived to reduce occupational accidents in the research area.

2.4. Determine sample size

Prior to carrying out a survey, it is essential to determine the required number of samples to serve as a foundation for data collection. The calculation of the number of samples is based on the mathematical Formula (2.1) outlined in [33].

$$n = \frac{z^2 \cdot s^2}{(\mu - \overline{x})^2} \tag{2.1}$$

where: s is the standard deviation of the sample; z is the value representing the required confidence level, with a confidence level of 95% or 99% the corresponding value of z is 1.96 or 2.58; $(\mu - \overline{x})$ is half the width of the required confidence level.

Furthermore, Gorsuch highlighted that factor analysis necessitates a minimum of 200 observations. Or Hachter demonstrated that the sample size must be a minimum of five times the observed variable. Bollen determined that the minimum sample ratio required for estimating a parameter is 5 samples.

In the context of the research topic, the author has determined an appropriate sample size of 250 samples, drawing on the ability and implementation time of the topic, as well as building upon the research findings of Gorsuch.

2.5. Guidelines for choosing participants for the questionnaire

Personnel and supervisors engaged in initiatives within the Mekong Delta regions.

Work experience is categorised into: < 3 years, 3 to 5 years, 5 to 7 years, and more than 7 years.

Qualifications in construction from a university or higher institution.

Data selection:

– Exclude questionnaires where respondents provided irrelevant answers regarding the significance of occupational safety in the context of construction projects in the Mekong Delta.
– Exclude questionnaires from respondents who were not part of the study conducted by the author.

2.6. Survey investigation plan

The Mekong Delta comprises 13 administrative units, which include one city directly governed by the Central Government, Can Tho City, along with 12 provinces: Long An, Dong Thap, An Giang, Tien Giang, Ben Tre, Vinh Long, Tra Vinh, Hau Giang, Kien Giang, Soc Trang, Bac Lieu, and Ca Mau. The author engaged with 250 survey forms, establishing connections or receiving introductions from esteemed experts across various departments, branches, and construction companies to distribute the surveys (shown in Figure 2).

Fig. 2. Map of the Mekong Delta region [internet]

2.7. Factors affecting construction on labor safety

Examine the findings of research pertaining to the subject. These studies highlight various factors that influence labour safety overall, with a specific focus on the effects of construction activities on labour safety within the Mekong Delta region. Analyse the elements that influence labour safety in construction environments. The factors serve as the foundation for expert discussions, guiding the selection of influencing elements to incorporate into the survey form.

3. Results and discussion

3.1. Evaluate the results from the survey

Drawing from prior relevant studies, insights from experts in the construction sector, and an analysis of the current conditions in the Mekong Delta region (see Table 2), the author identified 19 factors that influence labour safety at construction sites. The following factors are categorised as such:

- Group 1: Technical measures in construction
- Group 2: Machinery and equipment for construction
- Group 3: Management of Contractors
- Group 4: Workers
- Group 5: Additional considerations

Table 2. Elements influencing labour safety in construction projects within the Mekong Delta [Authors]

No	Effect factors
1	Approved construction technical measures, yet not appropriate for real construction conditions.
2	The technical measures for construction have yet to receive approval.
3	Insufficient organisation to assess and review safety conditions of construction technical measures prior to implementation
4	Uninspected construction equipment has been put into operation.
5	Construction machinery and equipment undergo inspection, though they are not tested prior to being utilised.
6	Utilising the machine for its designated function
7	Operating the machine beyond its limits
8	The construction unit's management capacity is limited, and there is a deficiency in experience with the application of new technology in construction.
9	The contractor employs unsuitable construction equipment.
10	There are no safety measures implemented for construction projects.
11	The contractor failed to supply protective equipment for the workers.
12	Utilising low-quality scaffolding formwork
13	Construction may not adhere to technical instructions, or the technical instructions may not be properly established.
14	Seasonal workers lack training in occupational safety.
15	Insufficient observation and focus in the workplace
16	Noncompliance with established safety regulations as outlined
17	Inadequate use of protective equipment pertinent to the tasks being carried out
18	Weather
19	Working environment around

The author developed a survey questionnaire incorporating various factors that influence labour safety at construction sites.

The survey was conducted over a period of 5 months across 13 provinces in the Mekong Delta. The authors compiled a list of individuals to be surveyed, along with their contact details, through their friends and work associates. The author subsequently carried out a direct survey, distributing the questionnaires through email to officials who were unable to meet face-to-face. Following the direct survey, the data gathered included:

– Total number of questionnaires distributed: 250 questionnaires.
– Total number of questionnaires collected: 250.
– The total count of valid questionnaires is 246.

The author processed the data from 246 valid questionnaires to prepare for the subsequent steps of analysis.

Participant details (Table 3, Figure 3).

Table 3. Job title [Authors]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Management staff	71	28.9	29.1	29.1
	Technical staff	166	67.5	68.0	97.1
	Support staff, advisors	6	2.4	2.5	99.6
	others	1	0.4	0.4	100.0
	Total	244	99.2	100.0	
Missing	System	2	0.8		
	Total	246	100.0		

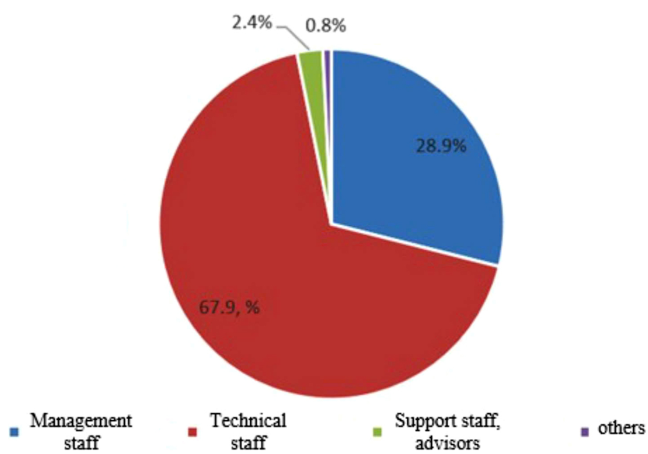

Fig. 3. Classification of respondents by job position [Authors]

Classification based on years of experience (Figure 4). This study reveals that the majority of respondents possess over 7 years of working experience, representing the largest segment at 56%. Meanwhile, individuals with 5–7 years of experience make up 34%, and those with 3–5 years account for 10%. Notably, there are no respondents with less than 3 years of experience. Most respondents possess work experience that is at least equivalent to a level 2 certificate or higher. The information gathered from the survey is objective and possesses significant practical value.

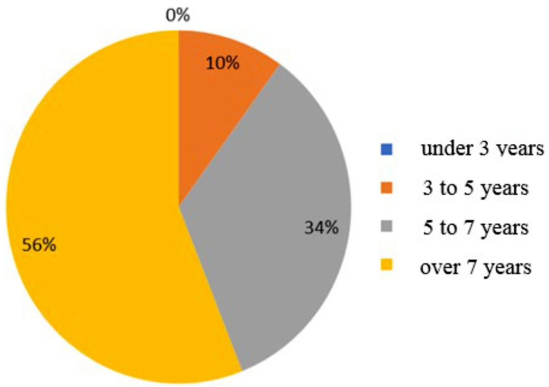

Fig. 4. Classification of respondents by years of experience [Authors]

Classification based on project implementation position (Table 4, Figure 5).

Table 4. Project implementation location [Authors]

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	Investor	51	20.7	20.9	20.9
	Consulting unit	136	55.3	55.7	76.6
	Contractor	57	23.2	23.4	100.0
	Total	244	99.2	100.0	
Missing	System	2	0.8		
	Total	246	100.0		

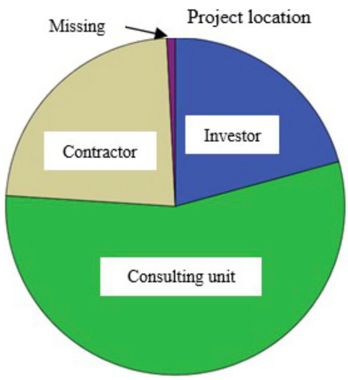

Fig. 5. Classification of respondents by project implementation location [Authors]

3.2. Assessment of factors affecting construction on labor safety at construction sites

The author provides content in the section regarding the assessment of factors influencing labour safety at construction sites in the Mekong Delta region, derived from a data set comprising 246 observation samples collected by the author. The author initially proposed a total of 19 observed variables, organised into 5 factor groups.

The initial factor is the factor: Construction technical measures, which include a total of three observed variables ranging from YT1 to YT3.

The second factor pertains to construction machinery and equipment, organised from YT4 to YT7, encompassing a total of four observed variables.

The third factor is Contractor management, which includes the contribution of six observed variables, ranging from YT8 to YT13.

The fourth factor is as follows: Workers are organised from YT14 to YT17, encompassing a total of 4 observed variables.

The fifth factor is identified as follows: Other factors are organised from YT18 to YT19, encompassing a total of 2 observed variables.

Identifying the factors that influence labour safety at construction sites in the Mekong Delta region serves as a crucial foundation for research aimed at proposing effective solutions. This research seeks to enhance efforts in reducing labour accidents, ultimately minimising the adverse effects of such incidents on the local economy and society. The factors will be incorporated into the Cronbach's Alpha reliability test.

Cronbach's Alpha Analysis: The study incorporated 19 observed variables categorised into 5 groups of factors to assess the influences on labour safety at construction sites in the Mekong Delta region. Presented below in Table 7 are the results of Cronbach's Alpha (Table 5).

Table 5. Cronbach's Alpha results [Authors]

Factors affecting	**Corrected Item-Total Correlation**	**Cronbach's Alpha if Item Deleted**
Group1: Technical measures for construction and Cronbach's Alpha = 0.621		
YT1. Technical measures for construction have been approved, yet they are not appropriate for the actual conditions on site.	0.424	0.535
YT2. The technical measures for construction have yet to receive approval.	0.422	0.532
YT3. Insufficient organisation to assess and review safety conditions of construction technical measures prior to implementation	0.447	0.500
Group 2: Cronbach's Alpha for Construction Equipment = 0.756		
YT4. Uninspected construction equipment has been put into use.	0.557	0.697

Continued on next page

Table 5 – *Continued from previous page*

Factors affecting	Corrected Item-Total Correlation	Cronbach's Alpha if Item Deleted
YT5. Construction machinery and equipment undergo inspection, though they are not tested prior to being utilised.	0.533	0.711
YT6. Utilising the machine for its designated function	0.536	0.709
YT7. Operating the machine beyond its limits	0.588	0.680
Group 3: Contractor Management Cronbach's Alpha = 0.801		
YT8. The construction unit's management capacity is limited, and there is a deficiency in experience regarding the application of new technology in construction.	0.483	0.789
YT9. The contractor employs unsuitable construction equipment.	0.570	0.767
YT10. There are no safety measures in place for construction projects.	0.669	0.742
YT11. The contractor failed to supply protective equipment for the workers.	0.520	0.779
YT12. Utilising substandard scaffolding formwork	0.557	0.770
YT13. Construction not adhering to technical instructions or lack of established technical instructions	0.551	0.772
Group 4: Worker Cronbach's Alpha = 0.850		
YT14. Seasonal workers lack training in occupational safety.	0.630	0.835
YT15. Insufficient observation and focus in the workplace	0.719	0.797
YT16. Noncompliance with established safety regulations	0.712	0.801
YT17. Inadequate use of appropriate protective equipment related to the tasks being carried out	0.700	0.805
Group 5: Other factors Cronbach's Alpha = 0.895		
YT18. Weather	0.810	
YT19. The atmosphere in the workplace	0.810	

The Cronbach's Alpha test (shown in Table 7) was conducted for 19 observed variables across 5 factor groups: (1) Construction technical measures, (2) Construction machinery and equipment, (3) Contractor management, (4) Workers, and (5) Other factors. The results indicate that all factors exhibit high Cronbach's Alpha coefficients, specifically 0.621, 0.756, 0.801, 0.850, and 0.895 for the 5 factor groups. The total correlation coefficient for all observed variables varies between 0.422 and 0.810, indicating that all 19 observed variables are incorporated in the exploratory factor analysis (EFA). In particular, when evaluating Cronbach's Alpha for the factor group "Construction technical measures" using three observed variables from YT1 to YT3, the Cronbach's Alpha coefficient for the factor achieved a value of 0.621, which is greater than 0.6. This indicates that the scale is entirely appropriate for factor analysis. The total correlation coefficient of the observed variables exceeds 0.3. Next, testing Cronbach's Alpha for the factor "Construction machinery and equipment" (YT4 to YT7) yielded a Cronbach's Alpha coefficient of 0.756, which is significantly higher than the acceptable threshold of 0.6, indicating that the scale meets the standard. The proposed model's observed variables exhibit a total correlation coefficient exceeding 0.3. Consequently, no observed variables associated with the factor "Construction machinery and equipment" (YT4 to YT7) were removed from the research model at this stage.

The Cronbach's Alpha test for the factor group "Contractor Cronbach's management," which includes 06 observed variables from YT8 to YT13, yielded a Cronbach's Alpha coefficient of 0.801, exceeding the threshold of 0.6. This indicates that the scale is entirely appropriate for factor analysis. The total correlation coefficient of the observed variables exceeds 0.3.

The Cronbach's Alpha test for the factor group "Worker," which includes four observed variables from YT14 to YT17, yielded a Cronbach's Alpha coefficient of 0.850, exceeding the threshold of 0.6. This indicates that the scale is highly appropriate for factor analysis. The total correlation coefficient of the observed variables exceeds 0.3.

The test result for the factor "other factors" with observed variables from YT18 to YT19 showed that the Cronbach's Alpha coefficient reached a value of 0.895, which is greater than 0.6, indicating that the scale meets the standard. The total correlation coefficient of the observed variables is 0.81, indicating that no observed variables are eliminated.

Consequently, following the assessment of Cronbach's Alpha for the observed variables, all variables remain included in the model. A total of 19 observed variables were incorporated into the exploratory factor analysis model.

3.3. Exploratory factor analysis EFA

Following the assessment of Cronbach's Alpha, the research performed exploratory factor analysis to consolidate and categorise observed variables into significant factors, thereby improving the explanatory power of the utilised factors. Exploratory factor analysis (EFA) is a quantitative analysis technique employed to condense a large array of interrelated measurement variables into a more manageable set of factors. This process aims to enhance the interpretability of the data while preserving the majority of the information contained in the original variable set [34]. Factor analysis finds application in various scenarios: Identifying aspects or factors that correlate within a set of variables, determining a relatively small number of new variables that are uncorrelated with one another for subsequent multivariate analysis, or selecting a few prominent variables from a larger set for use in later multivariate analyses [29].

This study employs Principal Components Analysis (PCA) with Varimax rotation. The Kaiser–Meyer–Olkin value falls within the range of $0.5 \leq \text{KMO} \leq 1$ (Table 6), and the significance level is indicated by a coefficient of Sig. = 0.000, confirming statistical significance. Furthermore, a Multivariate Data Analysis score of 0.5 indicates a good quality observed variable, with a minimum threshold of 0.3 [33]. The research model in this study will yield the following three tables from the first exploratory factor analysis (EFA).

Table 6. KMO and Bartlett's Test [33]

Kaiser–Meyer–Olkin Measure of Sampling Adequacy		0.806
Bartlett's Test of	Approx. Chi-Square	2030.997
Sphericity	Df	171
	Sig.	0.000

The initial results of the EFA analysis indicate that all factor loading coefficients exceed 0.5. Consequently, the factors guarantee convergent and discriminant values when conducting an analysis of EFA. Furthermore, EFA investigates the connections between variables across various groups (factors) to identify observed variables that are associated with multiple factors. Furthermore, EFA analysis assists the study in reorganising the observed variables in a manner that is more suitable than the originally suggested model. The analysis results indicate that the observed variables YT4 and YT5 are appropriately categorised within factor group 1: Construction technical measures. Specifically, YT4 refers to construction machinery and equipment that have not been inspected and put into use, while YT5 pertains to construction machinery and equipment that have been inspected but not checked prior to use. These two factors align closely with factor group 1, as any work accidents arising from them are likely to occur during the construction phase. Consequently, by modifying the variables in the factors, these independent factors remain unchanged, neither increased nor decreased.

Therefore, the initial group of factors consists of a total of 05 observed variables, which are: YT1, YT2, YT3, YT4, and YT5. This initial set of factors aims to clarify the issues concerning construction technical measures that impact labour safety at construction sites in the Mekong Delta region. This initial set of factors pertains to unapproved construction technical measures or approved measures that are inappropriate for the actual construction conditions, as well as uninspected construction machinery and equipment that are in use, or inspected machinery and equipment that have not undergone checks prior to being utilised. Furthermore, the absence of a structured approach to inspect and assess the safety conditions of construction technical measures prior to their application and construction is a significant factor that warrants attention within this group of considerations. The initial factor is referred to as "Construction technical measures" and is labelled X1.

The second group of factors consists of two observed variables: YT6 and YT7. This second group of factors elucidates the influence of construction machinery and equipment on labour safety at construction sites in the Mekong Delta region. The use of machinery that does not align with its intended function or exceeds its capacity. Consequently, the author designates the group of factors as "Construction machinery and equipment", referred to as X2. The third category of factors is referred to as "Contractor management" and is labelled as X3. The contractor management factor group consists of six observed variables: YT8, YT9, YT10, YT11, YT12, and RR13. The variables identified in the third group of factors pertain to issues like the use of inadequate formwork and scaffolding, the absence of a design for labour safety measures in construction projects, and the failure to adhere to technical instructions or the lack of established technical guidelines. Furthermore, it pertains to the contractor's failure to supply labour protection equipment for workers and the use of unsuitable construction equipment by the contractor. Simultaneously, the management capabilities of the construction unit and the lack of experience in implementing new technologies in construction will impact labour safety at construction sites in the Mekong Delta region. This is also one of the factors highlighted by the author in his research.

The fourth group of factors consists of four observed variables: YT14, YT15, YT16, and YT17. This group encompasses the factors related to the worker aspect. Workers do not completely adhere to the prescribed safety regulations and do not fully utilise the protective equipment associated with their tasks. Workers often exhibit a lack of observation and attention to their tasks, which impacts labour safety at the construction site. Furthermore, the employment of seasonal workers lacking training in labour safety also contributes to the research issue. Consequently, the fourth factor group referred to as "Workers" is designated as X4. The fifth factor group consists of a factor group created with two observed variables, namely: YT18 and YT19. This is a factor group that pertains to other factors. The weather and the surrounding working environment significantly influence labour safety at construction sites in the Mekong Delta region. The fifth factor group, referred to as "Other factors", is designated as X5.

3.4. Factor score matrix analysis

Following the exploratory factor analysis (EFA), 19 observed variables were identified, categorised into 05 groups of factors that influence labour safety at construction sites in the Mekong Delta region. The study then performed a factor score matrix analysis to assess the extent to which observed variables contributed to each group of factors within the model (Table 7).

The coefficient of the first factor group X1 is articulated for the factor "Construction technical measures" using the following expression: $X1 = 0.305 \cdot YT1 + 0.332 \cdot YT2 + 0.273 \cdot YT3 + 0.24 \cdot YT4 + 0.274 \cdot YT5$. The analysis reveals that the observed variable "YT2. Construction technical measures not yet approved "exerts the most significant influence on this factor group. The coefficient of the second factor group X2, which includes 2 observed variables, is expressed in the following manner: X2 equals $0.515 \cdot YT6 + 0.46 \cdot YT7$. This coefficient represents the factor "Construction machinery and equipment" in the research model discussed in the topic. The findings from expression X2 indicate that the observed variable "YT6. Using the machine for the wrong purpose" contributes the most significant coefficient (0.515) to the model. This also clarifies that utilising the machine for inappropriate purposes will lead to occupational safety hazards.

The coefficient for the factor "Contractor management" or X3 is expressed as follows: $X3 = 0.178 \cdot YT + 0.305 \cdot YT9 + 0.263 \cdot YT10 + 0.333 \cdot YT11 + 0.345 \cdot YT12 + 0.233 \cdot YT13$. It is evident that the variable "YT11. Contractor does not provide workers with protective equipment" exerts the most significant influence on the third factor in the model.

The coefficient of the fourth factor, represented by X4, is as follows: "Workers". X4 equals 0.330 times YT14 plus 0.305 times YT15 plus 0.314 times YT16 plus 0.320 times YT17. This indicates that the observed variable "YT14. Seasonal workers have not been trained in

Table 7. Results of factor score matrix analysis [Authors]

Observation variable	**Factor**				
	1	**2**	**3**	**4**	**5**
Construction technical measures					
YT1. Technical measures for construction have been approved, yet they are not appropriate for the actual conditions on site.	0.305				
YT2. The technical measures for construction have yet to receive approval.	0.332				
YT3. Insufficient organisation to assess safety conditions of construction technical measures prior to implementation	0.273				
YT4. Uninspected construction equipment has been put into use.	0.24				
YT5. Construction machinery and equipment undergo inspection, though they are not tested prior to being utilised.	0.274				
Machinery and equipment used in construction					
YT6. Utilising the machine for its designated function		0.515			
YT7. Operating the machine beyond its limits		0.46			
Contractor Management					
YT8. The construction unit's management capacity is limited, and there is a deficiency in experience regarding the application of new technology in construction.			0.178		
YT9. The contractor employs unsuitable construction equipment.			0.305		
YT10. There are no safety measures in place for construction projects.			0.263		
YT11. The contractor failed to supply protective equipment for the workers.			0.333		
YT12. Utilising substandard scaffolding formwork			0.345		
YT13. Construction may not adhere to technical instructions, or there may be a lack of established technical instructions.			0.233		
Worker					
YT14. Seasonal workers lack training in occupational safety.				0.330	
YT15. Insufficient observation and focus in the workplace				0.305	
YT16. Noncompliance with established safety regulations				0.314	
YT17. Inadequate use of appropriate protective equipment related to the tasks being carried out				0.320	
Other factors					
YT18. Weather					0.498
YT19. The atmosphere in the workplace					0.468

occupational safety" exerts the most significant influence among the four observed variables of the fourth factor – Workers. This accurately evaluates the reality of occupational accidents at construction sites in the Mekong Delta region, reflecting the regional characteristics of workers who primarily engage in labour according to the agricultural season. During the rice season, they will refrain from construction work and concentrate on the crop season instead. Once the crop season concludes and work is scarce, they will transition to construction jobs.

The coefficient of the final factor X5 is expressed as: $X5 = 0.498 \cdot YT18 + 0.468 \cdot YT19$. This demonstrates that the observed variable "YT18. Weather" exerts the greatest influence among the two observed variables of the fifth factor – Other factors.

The survey results and the expressions X1, X2, X3, X4, and X5 indicate that all observed variables positively influence each factor in the model. Consequently, any changes to the observed variables in the model will influence labour safety at construction sites in the Mekong Delta region. Thus, we can depend on the extent of this impact to manage and suggest measures for enhancing labour safety at these sites.

3.5. Suggesting measures to minimise workplace accidents in construction in the Mekong delta

Foundation for suggested resolution: The study aims to propose effective solutions for reducing occupational accidents at construction sites in the Mekong Delta region through the collection and analysis of relevant data. To achieve thorough and evidence-based solutions, the topic elucidates the foundation for developing these solutions. The findings from the research on the present circumstances have highlighted elements influencing occupational safety in construction environments. The influence of each observed variable (factor) on the group of factors is also examined concurrently. The study identified five groups of factors influencing occupational safety at construction sites in the Mekong Delta region: Construction technical measures (X1), Construction machinery and equipment (X2), Contractor management (X3), Workers (X4), and Other factors (X5).

Collection of solutions regarding construction technical measures: The construction method refers to the sequence and approach taken to complete a specific project, starting from the initial phase and concluding with the handover. This method must outline aspects such as time efficiency and preventive measures (including accident and fire prevention) to ensure the project is finished promptly, effectively, and safely. Every project will utilise a distinct construction method tailored to meet the specific requirements of that project. Within the realm of construction technical measures, five factors influence labour safety at construction sites in the Mekong Delta region: YT1. Approved construction technical measures that do not align with actual construction conditions; YT2. Construction technical measures that lack approval; YT3. Insufficient organisation for inspecting and evaluating the safety conditions of construction technical measures prior to application; YT4. Construction machinery and equipment that have not undergone inspection before use; YT5. Construction machinery and equipment that are inspected but not verified before being utilised. Based on the findings presented in section 3.2, the authors suggest measures aimed at mitigating occupational accidents associated with this set of factors:

1. Before commencing construction, all projects are required to have an approved construction organisation design and construction design for the works involved. The aim of creating a construction design (TKTC) is to identify the most efficient construction method that minimises labour, shortens construction duration, reduces costs, decreases material usage, enhances the quality of construction work, and ensures the safety of workers.
2. For approved construction technical methods that do not align with actual construction conditions, it is essential to form a contractor expert team comprising skilled engineers to reassess the current status of the project and provide well-considered proposals and modifications prior to commencing construction.
3. It is essential that all construction technical methods undergo inspection and assessment for safety conditions prior to implementation, and that they are closely monitored throughout the implementation process.
4. The machinery and equipment utilised must undergo inspection, possess a comprehensive machine history, and be licensed for use in accordance with the regulations set forth by the Ministry of Labour.
5. Machinery and equipment used in construction must undergo inspection, installation, and testing to ensure quality, with alternative plans in place prior to construction.
6. It is essential that all machinery and equipment on the construction site maintain a tracking record to guarantee compliance with safety and quality standards at all times. On extensive construction sites, a colour-coded stamp system that changes every quarter can be employed to enhance the management of machinery and equipment. For instance: quarter I – blue stamp, quarter II – red stamp, quarter III – purple stamp. At the conclusion of each quarter, the records and documents will be reviewed, and the machinery and equipment on-site will be inspected prior to applying a new stamp. Machinery and equipment failing to meet safety requirements will remain unstamped until they are either repaired or removed from the construction site, and their use is prohibited. This Stamp system allows for the straightforward identification of machines and equipment that fail to comply with safety standards.

3.6. Group of solutions on machinery and equipment for construction

The collection of machinery and equipment utilised in construction encompasses the following elements: YT6. Utilising the machine for an incorrect purpose; YT7. Employing the machine beyond its intended capacity. The suggested solution in this group is as follows:

Contractors must thoroughly examine the procedures, criteria for machinery inspection, and the functions and capacity of the equipment before bringing it to the construction site. It is essential to refrain from using the machine for inappropriate purposes. When seeking to utilise machinery and equipment for tasks that do not align with their intended use, such actions must receive approval from the safety officer and require careful supervision.

Avoid operating the machine beyond its designated capacity. Ensure that there is a machine instruction manual available and that supervision is always present.

3.7. Contractor management solutions group

The management team of the contractor encompasses the following elements: YT8. The construction unit's management capacity is limited, and there is a deficiency in experience with the application of new technology in construction; YT9. The contractor employs unsuitable construction equipment; YT10. Absence of labour safety measures in project construction; YT11. The contractor fails to supply labour protection equipment for workers; YT12. Utilisation of substandard formwork and scaffolding; YT13. Construction practices do not adhere to technical instructions, or such instructions are not established.

A successful and sustainable construction project involves various elements, ranging from the initial concept and design to the actual implementation of the construction. The construction contractor plays a crucial role in the process of ensuring a project's success. To guarantee that the team of workers and employees operates efficiently, the contractor must clearly and firmly assign responsibilities to each individual and each role. The contractor is also required to ensure the transfer of all essential technical procedures to the relevant locations, enabling them to provide mutual support throughout the construction process:

- Prior to dispatching workers to the construction site, the contractor will arrange for retraining, testing, and classification of workers tailored to each individual and specific group of individuals. Supply information and safety gear for labour protection. The contractor will place greater emphasis on management and construction instructions, particularly for general workers involved in short-term recruitment.
- The contractor is required to conduct regular inspections to ensure the safety of machinery and equipment. Additionally, construction machinery and equipment should be utilised for their intended functions to maintain productivity.
- It is essential to establish safety measures during construction to guarantee the safety of labourers. Approved measures by superiors should be communicated effectively and training provided for the workers directly involved in construction.
- Workers must be equipped with essential labour protection during construction, including fabric shoes, safety belts, protective clothing, safety helmets, and more.
- It is essential to evaluate the load-bearing capacity of formwork and scaffolding prior to their utilisation. When installing any structure, it is essential to calculate and verify the load-bearing capacity based on two conditions.
- Establishing technical instructions for each work is essential. At every stage of construction, it is essential to meet technical requirements, utilise appropriate materials, and engage skilled personnel. Those who suggest construction methods should possess knowledge, experience, keen observation, and an understanding of various construction types. For each type of project, it is essential to propose the most suitable and efficient construction method. Outdated methods that no longer fit the current context should be avoided. Promote the understanding and integration of global large-scale projects to enhance the domestic construction sector.
- Form an inspection team to evaluate labour safety at the construction site.

3.8. Worker solutions group

Workers at construction sites play a crucial role in the construction and installation of various projects, including civil houses, high-rise buildings, infrastructure, bridges, roads, and numerous other construction endeavours. They play a crucial role in the development of infrastructure and other significant projects, ensuring that these initiatives are finished on time and adhere to safety and quality standards. Construction sites present numerous risks and hazards for workers, inherent to the nature of the industry. To reduce risks and guarantee the safety of workers, the authors suggest several solutions including:

– The best approach is to ensure that workers grasp the significance of occupational safety. Therefore, prior to dispatching workers to the construction site, contractors should arm themselves with knowledge regarding occupational safety and provide clear instructions on the use of safety equipment. Particularly regarding seasonal workers, it is essential to focus more on management and construction guidelines.
– Workers are required to adhere to labour safety regulations throughout the entire working process at construction sites. Safety measures and labour safety regulations should be prominently displayed at the construction site for all to see and adhere to; hazardous areas on the construction site must be marked with instructors and warnings to avert accidents. Sanctions are in place to ensure that workers adhere strictly to labour safety regulations. It is strictly prohibited for anyone to consume alcohol, beer, smoke, or use any stimulants that may induce nervous tension during working hours at the construction site.

3.9. Group of solutions on other factors

Construction is a unique industry where workers frequently operate outdoors, particularly in elevated positions, in hot and humid environments, and in areas with severe weather conditions. The Mekong Delta is situated in the heart of Asia's tropical monsoon region. From May to the end of September, it experiences the influence of the southwest monsoon, bringing humidity and rainfall, marking the rainy season. In contrast, from November to mid-March of the following year, the northeast monsoon from the mainland results in drier and less rainy conditions, defining the dry season from October to November. Additionally, from September to March of the following year, morning and evening tides occur.

Providing sufficient drinking water for workers is essential, as high temperatures and sunny conditions can raise body temperature, resulting in excessive sweating. It is essential for workers to promptly rehydrate by consuming adequate amounts of water; therefore, a supply of drinking water must always be available on the construction site. The scheduler needs to be aware of climatic conditions to organise work in a way that avoids adverse weather for the tasks at hand. If the work continues due to project requirements, the contractor must implement specific measures to mitigate the effects of weather conditions. This includes ensuring comfortable working conditions by supplying appropriate clothing and protective equipment to safeguard workers from the impacts of high temperatures. Utilise the cooler temperatures for outdoor tasks, reserve the hotter days for indoor activities, or strategically position your work area based on the sun's direction.

4. Conclusions

Based on the results of the study lead to the following conclusions:

Ensuring safety in construction is consistently a primary focus. It is the duty of investors, contractors, and workers involved in construction. To ensure safety and reduce incidents that impact the health of construction participants, assets, and equipment, related units must implement preventive measures from the outset. Both workers and employers should equip themselves with fundamental knowledge to safeguard their health and assets. The study identified five groups of factors, comprising 19 elements, that influence labour safety during the construction process at sites in the Mekong Delta region. It also proposed targeted solutions aimed at reducing labour accidents in these construction environments. The study additionally put forward several recommendations for units, including: It is essential for investors to oversee and monitor the execution of construction safety measures carried out by contractors. Clear disciplinary regulations exist, including fines or prosecution, for relevant units involved in construction sites. The design consulting unit emphasises that safety measures should be closely aligned with the actual construction conditions during the design process. Contractor: Suggest and implement labour safety measures for individuals, machinery, assets, and the overall project. Mandatory regulations must be established to ensure that workers who lack training in labour safety and are not fully equipped with protective equipment are prohibited from entering the construction site. Consistently dispatch employees to training programs focused on contemporary construction technology, followed by preparing workers prior to the commencement of construction activities on-site. It is essential to conduct labour safety training for all groups of workers involved in production on the construction site on a periodic and regular basis. Workers are required to adhere to the labour safety regulations set forth by the construction unit, remain vigilant about their personal safety while on the job, and ensure they are fully equipped with the appropriate labour protection gear for each specific task. Construction inspectors are required to conduct regular inspections and impose fines for unsafe labour practices at construction sites.

References

[1] A. Albert, B. Pandit, et al., "Does the potential safety risk affect whether particular construction hazards are recognized or not?", *Journal of Safety Research*, vol. 75, pp. 241–250, 2020, doi: 10.1016/j.jsr.2020.10.004.

[2] R.U. Farooqui, F. Arif, and S.F.A. Rafeeqi, "Safety Performance in Construction Industry of Pakistan", in *First International Conference on Construction in Developing Countrie*s. Karachi, 2008, vol. 2, pp. 74–87.

[3] J.M.J. Wilson and E. Koehn, "Safety management: problems encountered and recommended solutions", *Journal of Construction Engineering and Management*, vol. 126, no. 1, pp. 77–79, 2020, doi: 10.1061/(ASCE)0733-9364(2000)126:1(77).

[4] W. Drozd, "Cluster analysis in research of accident rate in construction sector", *Archives of Civil Engineering*, vol. 64, no. 3, pp. 159–172, 2018, doi: 10.2478/ace-2018-0036.

[5] P. Sivaprakash and S. Kanchana, "A study on statutory provisions for construction safety in India", *Archives of Civil Engineering*, vol. 64, no. 1, pp. 171–179, 2018, doi: 10.2478/ace-2018-0011.

[6] M. Kowalik and W. Drozd, "Evaluation of the influence of selected factors on hazardous events in construction", *Archives of Civil Engineering*, vol. 68, no. 2, pp. 377–390, 2022, doi: 10.24425/ace.2022.140648.

[7] E.W.L. Cheng, H. Li, D.P. Fang, and F. Xie, "Construction safety management: an exploratory study from China", *Construction Innovation*, vol. 4, no. 4, pp. 229–241, 2004, doi: 10.1108/14714170410815114.

[8] D.C. Ning, J.P. Wang, and G.D. Ni, "Analysis of Factors Affecting Safety Management in Construction Projects", in *International Conference on Management and Service Science*. Wuhan, China, 2010, pp. 1–5, doi: 10.1109/ICMSS.2010.5576911.

[9] N. Jokkaw and T. Tongthong, "Factors influencing on safety management status and evaluation of safety management status in construction projects in Cambodia", *ASEAN Engineering Journal*, vol. 5, no. 1, pp. 34–48, 2016, doi: 10.11113/aej.v5.15470.

[10] L. Yadi, N. Yan, and T.C. Wei, "Critical Success Factors for Safety Management Building Construction Projects in China", *Advances in Civil Engineering*, vol. 2018, no. 1, pp. 1–15, 2018, doi: 10.1155/2018/1516354.

[11] G.H.K. Priyadarshani and G. Karunasena, "Factors Affecting Construction Safety Management in Sri Lanka", in *International Research Conference on Sustainability in Built Environment*. Colombo, Sri Lanka, 2010, pp. 192–197.

[12] Q.Z. Yu, L.Y. Ding, C. Zhou, and H.B. Luo, "Analysis of factors influencing safety management for metro construction in China", *Accident Analysis & Prevention*, vol. 68, pp. 131–138, 2014, doi: 10.1016/j.aap.2013.07.016.

[13] A. Mohammadi, M. Tavakolan, and Y. Khosravi, "Factors influencing safety performance on con-struction projects: A review", *Safety Science*, vol. 109, pp. 382–397, 2018, doi: 10.1016/j.ssci.2018.06.017.

[14] A.O. Akinsola, K.F. Potts, I. Ndekugri, and F.C. Harris, "Identification and evaluation of factors influencing variations on building projects", *International Journal of Project Management*, vol. 15, no. 4, pp. 263–267, 1997, doi: 10.1016/S0263-7863(96)00081-6.

[15] S. Han, F. Saba, S. Lee, et al., "Toward an understanding of the impact of production pressure on safety performance in construction operations", *Accident Analysis & Prevention*, vol. 68, pp. 106–116, 2014, doi: 10.1016/j.aap.2013.10.007.

[16] B.H. Guo, T.W. Yiu, and V.A. González, "Identifying behaviour patterns of construction safety using system archetypes", *Accident Analysis & Prevention*, vol. 80, pp. 125–141, 2015, doi: 10.1016/j.aap.2015.04.008.

[17] Y. Feng, S. Zhang, and P. Wu, "Factors influencing workplace accident costs of building projects", *Safety Science*, vol. 72, pp. 97–104, 2015, doi: 10.1016/j.ssci.2014.08.008.

[18] D. Fang, C. Wu, and H. Wu, "Impact of the supervisor on worker safety behavior in construction projects", *Journal of Management in Engineering*, vol. 31, no. 6, 2015, doi: 10.1061/(ASCE)ME.1943-5479.0000355.

[19] M. Segbenya and E. Yeboah, "Effect of Occupational Health and Safety on Employee Performance in the Ghanaian Construction Sector", *Environmental Health Insights*, vol. 16, 2022, doi: 10.1177/11786302221137222.

[20] M. Novy and J. Novakova, "Protecting Occupational Health and Safety in Construction Companies in the Czech Republic", *Procedia Computer Science*, vol. 219, pp. 1793–1800, 2023, doi: 10.1016/j.procs.2023.01.475.

[21] N.L. Hai, "An investigation the impact of the construction executing into construction safety in Vietnam", *Journal of Science and Technology in Civil Engineering*, vol. 13(1V), pp. 66–74, 2019.

[22] T.H. Tuan, "Analysis of factors acffecting safety performance of labour construction", *CTU Journal of Science*, vol. 12, pp. 162–170, 2009.

[23] D.T. Sy, N.H. Dai, L.G. Huy, and N.H. Thanh, "Applying IoT technology integrating with helmets for safety management at construction sites", *Journal of Building Materials and Construction*, vol. 13, no. 1, pp. 112–117, 2023, doi: 10.54772/jomc.01.2023.445.

[24] N.T. Viet and H.Ng. Viet, "Building a framework for assessing the safety management on construction sites in HCM city", *Journal of Science and Technology - Industrial University of HCMC*, vol. 53, no. 5, pp. 16–28, 2021, doi: 10.46242/jstiuh.v53i05.4133.

[25] B.T. Tung, "Research on important factors affecting the implementation of occupational safety programs in construction projects in Vietnam", M.A. thesis, Ho Chi Minh City University of Technology, Vietnam, 2013.

[26] B.H. Phuong, "Combining EFQM model and SYSTEM DYNAMICS to improve safety culture", M.A. thesis, Ho Chi Minh City University of Technology, Vietnam, 2014.

[27] D.T. Duc, "Research on factors affecting labor safety costs and propose a quantitative forecasting model for labor safety costs in construction works in Ho Chi Minh City", M.A. thesis, Ho Chi Minh City University of Technology, Vietnam, 2017.

[28] V.C. Dam, *Research methodology*. Hanoi: Science and Technology Publishing House, 2005.

[29] H. Trong and C.N.M. Ngoc, *Analyzing research data with SPSS*. Statistical Publishing House, 2008.

[30] N.D. Tho, *Research Methods in Business*. Social Labor Publishing House, 2011.

[31] E. Cristobal, C. Flavián, and M. Guinaliu, "Perceived E-Service Quality (PeSQ) Measurement Validation and Effects on Consumer Satisfaction and Web Site Loyalty", *Managing Service Quality: An International Journal*, vol. 17, no. 3, pp. 317–340, 2007, doi: 10.1108/09604520710744326.

[32] P. Loc, *SPSS 26 User Guide - Applying quantitative analysis to writing theses and economic research topics*.

[33] J.F. Hair Jr., R.E. Anderson, R.L. Tatham, and W.C. Black, *Multivariate Data Analysis*, 7th ed. Macmillan Publishing Company, 2010.

[34] R. Fellows and A. Liu, *Research Methods for Construction*, 4th ed. Oxford: John Wiley and Sons Ltd, 2008.

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