JURNAL ILMIAH TEKNIK INDUSTRI
ISSN: 1412-6869 (Print), ISSN: 2460-4038 (Online)
Journal homepage: http://journals.ums.ac.id/index.php/jiti/index
doi: 10.23917/jiti.v21i1.17434

An Ergonomic Intervention to Redesign Fish Smoking Device of Home Industry

Robert Hutagalung[1a◆], Victor Oryon Lawalata [2b], Nikmans Hattu [3c]

Abstract. *Smoke and heat become the contributors for increasing temperature and humidity in the production room, and workload of workers, and decreasing work productivity of a smoked fish home industry in Hative Kecil Village, Ambon City, Indonesia. This paper was aimed to redesign a fish smoking device with ergonomic consideration for solving the problem. An ergonomic intervention method applied to redesign the device. Redesign process describe result of ergonomic assessment in to the stages of rational method in order to produce new design. Despite the environmental variable (temperature and humidity), 10 male workers (age 40-50 year) were assessed their characteristics consisting of personal, anthropometric, workload and work productivity data. Final results presented a decreasing temperature (15.03%), humidity (8.06%), and workload of workers (75.89%) while work productivity increased 88.92%. It concluded that the device redesign can improve temperature, humidity, workload of workers and work productivity in the smoked fish home industry.*

Keywords: *ergonomic intervention; workload; productivity; redesign; fish smoking device*

I. INTRODUCTION

The smoked fish home industry in Hative Kecil Village, Ambon City operates in a way that is vulnerable to the health of its workers. Production activities are carried out by 2-4 workers without changing personnel for more than 8 hours per day. This exposes workers to smoke and heat for long periods of time. Smoke from wood burning contains particles harmful to human health such as carbon monoxide, nitrogen dioxide, formaldehyde, acrolein, benzene, and respirable particles, which cause headaches, dizziness, weakness, disorientation and impairment of decision making in addition to respiratory and cardiovascular diseases (Adetona et al., 2016). The results of wood burning contain polycyclic aromatic hydrocarbons (Khpalwak et al., 2019), which are pollutants and carcinogen in nature (Jadoon et al., 2015) which can be carried away with smoke during fish smoking.

The impact of smoke and heat is contributed by the fish smoking equipment used in the home industry. Today, smoking device designs vary in dimensions for each home industry. Length between 1.5 - 2 m, width 60 - 80 cm, height 1.2 - 1.5 m. The fish holding capacity is between 8-10 fish per shelf, the number of racks (waya) is between 3-6 pieces with a maximum holding capacity (1 batch) between 24 - 50 fish slices or the equivalent of 12-25 fish. The average production time per batch was 159.8 minutes using an average of 84 pieces of wood or 7 bundles. The average daily production capacity reaches 300 fish (150 fish). The tool component consists of an iron pipe assembly forming a rectangular building without covering the tool body. As a result, the combustion smoke spreads throughout the room, raising the room temperature. Increased temperature can cause heat stress which results in increased health risks (Pradhan et al., 2019; Wesdock and Donoghue, 2019), risk of accidents or illnesses at work and a decrease in work productivity (Nerbass et al., 2019). Therefore, it is necessary to make efforts to

[1] Physics Department, Faculty of Mathematics and Natural Sciences, Pattimura University Ambon, Jl. Ir. M. Putuhena, Kampus Poka Ambon 97233
[2] Industrial Engineering Department, Faculty of Engineering Pattimura University Ambon, Jl. Ir. M. Putuhena, Poka Ambon Kampus 97233.
[3] Chemistry Department, Faculty of Mathematics and Natural Sciences, Pattimura University Ambon, Jl. Ir. M. Putuhena, Kampus Poka Ambon 97233.

[a] email: robert_hutagalung@yahoo.com
[b] email: lawalata.victor@gmail.com
[c] email: nickhattu@fmipa.unpatti.ac.id
◆ corresponding author

Submited: 03-02-2022 Revised: 30-05-2022
Accepted: 21-06-2022

reduce the impact of smoke and heat for fish smoking workers.

Overcoming the problem of smoke and heat could be done through the design of a fish smoking device. In the early stages of design, it is necessary to identify the technical and organizational conditions of the work process (Sławińska, 2020) and the needs of the users that are not being met by the current design (van den Bemt et al., 2019). The goal is to match human characteristics (workers) and working conditions using these tools (Lifu et al., 2019). This means that the interaction between workers and machines/equipment (ergonomic aspects) is an important consideration in design. Ergonomic intervention in the smoking device designed in this study aims to reduce the temperature and humidity in the production room and reduce workload, as well as increase work productivity.

II. Research Method

The research was employed a true-experimental design with a single group pre-test and post-test. We assessed 10 workers of smoked fish home industry in Hative Kecil village, Ambon-Maluku (sample size calculation using Colton, 1974). Characteristics of the sample are age ranging from 40 to 50 years, male sex, work continuously smoking fish, at least one year have worked in the smoked fish home industry, and are in good health as evidenced by a doctor's certificate.

Redesign of smoking device using rational methods (Cross, 2008) with ergonomic intervention. Colim et al. (2020) presents the intervention stages include (i) preliminary ergonomic assessment for current device; (ii) device redesign; (iii) ergonomic assessment of redesigned device; (iv) definition of ergonomic requirements for use of the new device. Redesign of smoking device using dimension measurement data of workers' bodies (Wiggermann et al., 2019; Hotzman *et al.*, 2011).

Room temperature and humidity as well as work load and productivity as parameters used in the assessment. Measurement of room temperature and humidity using standard measuring instruments (thermometer and hygrometer). There are several methods to measure workload level such as relative cardiovascular load (% CVL), cardiovascular strain (% CVS) and relative heart rate (% RHR) methods (Ismaila et al., 2013; Yang and Chan, 2001). Our research uses %RHR formula (Karvonen and Vuorimaa, 1988) and 220-age to estimate value of HR_{max} (Tanaka et al. 2001). Work productivity is measured as the ratio of output and unit of input (Beaton et al., 2009), which output as the sum of smoked fish and input as the difference in pulse before and after work.

III. Result and Discussion

Preliminary ergonomic assessment

The findings of the initial assessment are the characteristics of workers and work environment that are presented in Table 1. It shows a little variation in the age, weight, heigh and work experience. According to Weight Broca Index formula (Alejandro et al., 2018), workers tend to have a proportional body weight. They are skilled in smoking a fish based on their experience (more than 8 years in this job) and perform their work in the production room which is hot dan quite humid.

Table 1. Worker and work environment characteristics

	Mean	SD
Personal Variable		
Age (year)	45.10	8.77
Weight (kg)	57.10	1.43
Height (cm)	166.60	3.82
Work experience (year)	12.60	4.49
Environment Variable		
Production Room Temperature (^{0}C)	34.60	0.28
Production Room Humidity (%)	56.58	0.25

Figure 1. Fish smoking device (current design)

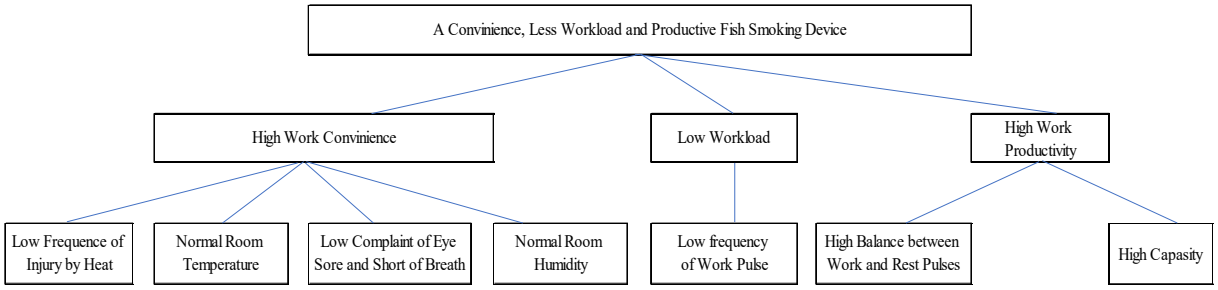


Figure 2. An objective tree of the device redesign

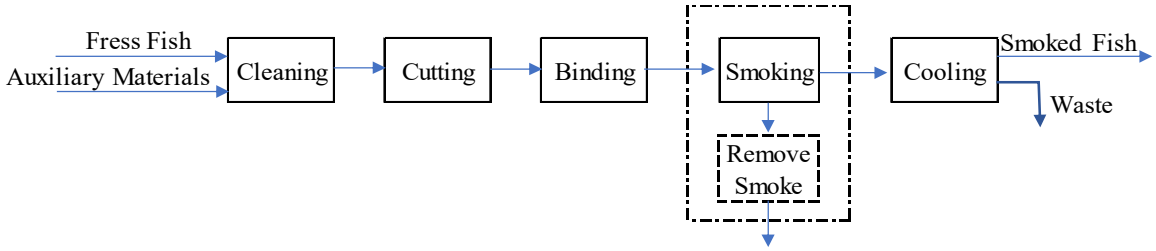


Figure 3. A box model of the device redesign

Contribution of the recent design of fish smoking device (Figure 1) are showed by low level of work productivity (Table 2). Using worker's age on Tabel 1, we found the level of HRmax = 220-45.10 = 174.90 pulse/minute and the level of worker's workload, %RHR = (139.61 - 79.14) / (174.90 – 79.14) = 63.15%.

Table 2. Workload and work productivity

	Mean	SD
Resting pulse frequency (pulse/minute)	79.14	0.65
Working pulse frequency (pulse/minute)	139.61	1.03
Work productivity (%)	1,785	0.473

Table 3. Dimensions of the worker's body

	Mean	SD	Percentile 95%
Height of body (cm)	152,75	5,05	160,00
Height of shoulder (cm)	125,90	5,13	133,33
Height of elbow (cm)	91,10	6,54	99,10
Height of knee (cm)	47,75	2,03	50,93
Length of elbow (cm)	32,50	1,68	35,10
Length of hand (cm)	16,30	1,03	17,78

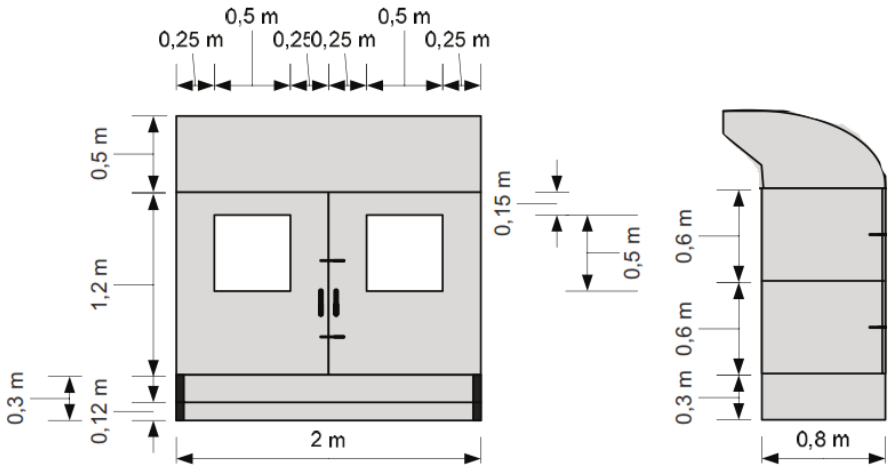
The structure of the tool design is currently the cause of complaints from workers. 100% of the research sample (workers) stated that smoke always interferes with the smooth running of their work. Workers often feel stinging and watery in their eyes and difficulty breathing due to inhaling air mixed with smoke from wood burning. Heat stroke on the skin around the fingers, wrists and forearms occurs every day (low frequency) due to contact with the components of the tool during the smoking process. This device uses an iron pipe as a major component material, which is an excellent conductor of heat. Workers respond to this phenomenon by spending a lot of time recovering, which increases the smoking time per batch of fish.

Device redesign

An ergonomic intervention based on preliminary assessment results of device redesign is to control the flow of smoke from wood burning and to use materials with low thermal conductivity. The goal of the redesign is to get a fish smoking device that provides work comfort, lighter workloads and encourages increased work productivity of workers (Figure 2). The working process of the device is very simple with the main function only for smoking fish with the supporting function is to remove smoke (Figure 3). Technically, this device must meet the design targets as shown in Figure 4. Its dimensions are determined considering the dimensions of the parts of the worker's body (Table 3).

Customer Needs and Benefit		Technical Response	Semi-Conductor Material	Volume	Room Temperature During Smoking Process	Temperature Level of Device's Body	Smoke Exhaust Flow	Shape that safe for use	Importance to Customer	Customer Satisfaction Performance	Competitive Satisfaction Performance	Planning Matrix Goal	Improvement Ratio	Sales Point	Row Weight	Normalized Row Weight
Work Convinience	Comforted Room Temperature				◎		◎		4	1,813	2,133	4	2,206	1	8,824	0,157
	Comforted Room Humidity				○		◎		4	2,613	2,120	4	1,531	1,2	7,347	0,131
	Less Complaint of Eye Sore and Short of Breath						◎		5	1,853	2,027	4	2,158	1,2	12,95	0,23
	Less Frequence of Injury by Heat		◎		△	◎		○	3	1,960	1,613	3	1,531	1	4,592	0,082
Workload	Less frequency of Work Pulse			◎	◎		○	△	3	1,840	2,187	3	1,630	1,2	5,87	0,104
Work Productivity	High Balance between Work and Rest Pulses				○		○		4	2,627	2,587	4	1,523	1,2	7,310	0,13
	High Capasity			◎				◎	5	2,133	1,973	4	1,875	1	9,375	0,167
	Priority		0,05126	0,17016	0,22424	0,05126	0,37408	0,12901								
	Unit		Yes/No	m2	0C	Score	Yes/No	Yes/No								
	Competitive Benchmarks		2	2	1	2	1	2								
	Own Performance		4	3	4	4	4	3								
	Targets		Yes	3,40	27	Warm	Yes	Yes								

Figure 4. A house of quality (HOQ) of the device redesign



a. Front view design b. Side view design

Figure 5. A 2-dimensional design of new device after redesign with ergonomic intervention

Redesign of the fish smoking device were carried out by adding a chimney and a wall covering. The distribution of hot smoke is concentrated out to the top through the chimney. In order to control excessive heat, this device is equipped with a chimney window and door that can be opened to enlarge the space for smoke exhaust. Result of device redesign provide a new prototype of the fish smoking device that shown in Figure 5 and Figure 6. It uses aluminum plate, a

a. Closed door view b. Front (open door view) c. Side (Open door view)

Figure 6. A new device after redesign with ergonomic intervention

semi-conductor material for body (thickness = 5 mm) and iron elbow for its frame (thickness = 5 mm). Its dimensions are 2 m length, 80 cm width and 2 m height including chimney (height before chimney = 1,5 m). The drain hole of the chimney is placed outside the production room to prevent the spread of hot smoke in the room. Observation of the condition of the fish when they are roughing through the glass on both doors, and fish processor will not be exposed by high heat radiation. This device consists of 5 shelves with a maximum capacity of 50 pieces of fish (10 piecies per shave).

Ergonomic assessment of redesign device

Design improvement of the smoking device by considering ergonomic intervention have improved the weaknesses of the previous design. Comparing to previous tests (Table 1 and 2), the test results of the new device (Table 4) show a decreasing level of temperature and humidity in the workshop, as well as the workload and productivity of the workers. Workers at 174.90 HRmax have reached 15.22 %RHR.

Table 4. Test result of fish smoking device after ergonomic intervention

	Mean	SD
Production Room Temperature (0C)	27.4	0.27
Production Room Humidity (%)	64.74	5.01
Resting pulse frequency (pulse/minute)	78.49	0.89
Working pulse frequency (pulse/minute)	93.16	1.39
Work productivity (%)	17.90	2.37

Discussion

Generally, workers are in the productive age (40-50 years). However, increasing age can reduce skeletal muscle mass and strength (Damiano et al., 2019; Calvani et al., 2014) which begins at the age of 39 along with decreasing aerobic capacity (Bridger, 1995). In contrast to the age of 20-30, muscle strength at the age of 65 years is 70-80% (Rodahl, 2005). It tends to have lower work performance (Grandjean, 1998). Workers have a relatively small variation in body weight, namely 57.10 ± 1.43 kg which is based on Aryatmo (1981), which is still in the ideal weight interval between 47.91 to 58.55 kg (53.23 ± 5.72 kg). Based on the average height and weight of workers, the results of the calculation of body mass index (BMI) = 20.57 kg/m2 which by NAASO and NHLBI (2000) are categorized as normal body weight.

The results of the assessment of the current device (Figure 1) found a contribution of design to form a work environment that is not ergonomic enough and low productivity. The current design that is open (without the cover of the tool body) causes the spread of hot smoke from the fumigation process into the workspace and creates a room temperature between 34.6 ± 0.28 0C with an air humidity of 56.68 ± 0.25% (Table 2). For the Indonesian region, a comfortable indoor temperature for people to work is between 24-27 0C with a humidity of 60 ± 5% (SNI 6390: 2011). This condition causes work discomfort. On the other hand, workers complained of sore eyes and difficulty breathing due to the burning smoke that enveloped the room. This condition requires workers to work hard to complete tasks, thereby increasing their workload. This is evidenced by the average working pulse frequency between 105.605 ± 1.03

pulse/minute which Grandjean (1998) categorized as a moderate workload level (between 100-125 beats/minute). Several studies have shown that a good pulse rate is between 77-86 beats/minute (Adiputra, 2008; Artayasa, 2007; Yuniarti, et al., 2005). For the resting pulse frequency of 79.137 ± 0.65 pulses/minute, the resulting work productivity average is 1.785 ± 0.473 pcs/pulse/minute.

The new device demonstrates the positive impact of ergonomic interventions. The new design test (Table 4) shows a 15.03% decrease in room temperature and an 8.06% increase in humidity. This environmental level parameter creates work comfort for workers to complete tasks more relaxed than before (workload decreased by 75.89% according %RHR). This change has led to an increase in work productivity by 88.92%. Complaints of difficulty in breathing and watery eyes decreased by 63.27%, while complaints of pain due to heat stroke decreased by 72.44%. The smoke stream in the new design moves up and out of the exhaust to the outside of the work space. Smoke entering the room occurs only when the device's door is opened to enter, bring out or change the position of the smoked fish.

IV. CONCLUSION

Ergonomic intervention on redesign is the major cause of decreasing weakness of the previous fish smoking device. After the use of the new device, it is confirmed that the new device can lower the temperature and humidity (in the production room), and the workload of workers, and rise the work productivity.

Further research is required to solve the limitation of the new device. It is need to understand about changing fish position without opening the device door, and making hot smoke last longer in the device thereby reducing wood usage.

REFERENCES

Adetona, O.; Reinhardt, T. E.; Domitrovich, J., Broyles, G., Adetona, A. M., Kleinman, M. T., Ottmar, R. D.; Naeher, L. P. (2016). "Review of the health effects of wildland fire smoke on wildland firefighters and the public", *Inhalation Toxicology: International Forum for Respiratory Research, 28* (3): 95-139, Taylor & Francis Group. DOI: 10.3109/08958378.2016.1145771.

Adiatmika, I. P.G. (2007). *Perbaikan Kondisi Kerja dengan Pendekatan Ergonomi Total Menurunkan Keluhan Muskuloskeletal dan Kelelahan serta Meningkatkan Produktivitas dan Penghasilan Perajin Pengecatan Logam di Kediri Tabanan*. Denpasar: Program Pascasarjana Universitas Udayana.

Adiputra, N. (1998). *Metodologi Ergonomi*. Denpasar: Universitas Udayana.

Alejandro, W. S.; Sofia, V. O.; Pablo, W. A. (2018). "Validation of the Broca Index as the Most Practical Method to Calculate the Ideal Body Weight", *Journal of Clinical Investigation and Studies, 1* (1).

Artayasa, I. M. (2007). *Pendekatan Ergonomi Total Meningkatkan Kualitas Hidup Pekerja Wanita Pengangkut Kelapa di Banjar Semaja Desa Antosari. Tabanan Bali* (Disertasi). Denpasar: Universitas Udayana.

Aryatmo, T. (1981). *Obesitas*. Jakarta: Komisi Pengembangan Riset Perpustakaan, Fakultas Kedokteran Universitas Indonesia.

Beaton, D.; Bombardier, C.; Escorpizo, R.; Zhang, W.; Lacaille, D.; Boonen, A.; Osborne, R. H.; Anis, A. H.; Strand, C. V.; Tugwell, P. S. (2009). "Measuring worker productivity: frameworks and measures", *The Journal of Rheumatology, 36* (9). DOI:10.3899/jrheum.090366.

Bridger, R. S. (1995). *Introduction to Ergonomics*. Singapore: Mc. Graw – Hill International

Calvani, R.; Martone, A. M.; Marzetti, E.; Onder, G.; Savera, G.; Lorenzi, M.; Serafini, E.; Bernabei, R.; Landi, F. (2014). "Pre-hospital dietary intake correlates with muscle mass at the time of fracture in older hip-fractured patients", *Frontiers in Aging Neuroscience, 6*, Art. 269. DOI: 10.3389/fnagi.2014.00269.

Colim, A.; Faria, C.; Braga, A. C.; Sousa, N.; Rocha, L.; Carneiro, P.; Costa, N.; Arezes, P. (2020). "Toward an ergonomic assessment framework for industrial assembly workstations – a case study", *Applied Science, 10*, 3048, DOI: 10.3390/app10093048.

Colton T. (1974). *Statistics in Medicine*. Boston: Litle Brown and Company.

Cross, N. (2008). *Engineering Design Method: Strategies for Product Design* (3th ed). West Sussex: John Wiley & Sons Ltd.

Damiano, S.; Muscariello, E.; La Rosa, G.; Di Maro, M.; Mondola, P.; Santillo, M. (2019). "Dual role of

reactive oxygen species in muscle function: can antioxidant dietary supplements counteract age-related sarcopenia", *International journal of Molecular Sciences, 20*, 3815. DOI: 10.3390/ijms20153815.

Grandjean, E. (1998). *Fitting the Task to the Man: a Texbook of Occupational Ergonomics*, 4th ed., London: Taylor & Francis.

Hotzman, J.; Gordon, C. C.; Bradtmiller, B.; Corner, B. D.; Mucher, M.; Kristensen, S.; Paquette, S.; Blackwell, C. L. (2011). *Measurer's Handbook: Us Army and Marine Corps Anthropometric Surveys, 2010-2011*. Massachusetts: U.S. Army Natick Soldier Research, Development and Engineering Center Natick.

Ismaila, S. O.; Oriolowo, K. T.; Akanbi, O. G. (2013). Cardiovascular strain of sawmill workers in South Western Nigeria. *International Journal of Occupational Safety and Ergonomics, 19* (4), 607-611.

Jadoon, W. A.; Kondo, H.; Sakugawa, H. (2015). "Distribution and source of particulate polycyclic aromatic hydrocarbons (PAHs) in air of Kamihaya, central Japan", *Geochemical Journal, 49*, pp. 207-17.

Karvonen, J.; Vuorimaa, T. (1988). "Heart rate and exercise intensity during sports activities practical application", *Sports Medicine, 5*, 303-312.

Khpalwak, W.; Jadoon, W. A.' Abdel-dayem, S. M.; Sakugawa, H. (2019). "Polycyclic aromatic hydrocarbons in urban road dust, Afghanistan: Implications for human health", *Chemosphere, 218*, 517-526.

Lifu, L.; Wei, L.; Ten, Z. H.; Meng, Z.; MengZhe, B. (2019). "*Model design and analysis improvement of CNC lathe based on ergonomics*", IOP Conf. Series: Materials Science and Engineering 573 012045. DOI:10.1088/1757-899X/573/1/012045.

NAASO and NHLBI. 2000. *Practical Guide to the Identification, Evaluation, and Treatment of Overweight and Obesity in Adults*. NIH Publication Number 00-4084.

Nerbass, F. B.; Moist, L.; Clark, W. F.; Vieira, M. A.; Pecoits-Filho, R. (2019). "Hydration status and kidney health of factory workers exposed to heat stress: a pilot feasibility study", *Annals of Nutrition & Metabolism, 74* (suppl 3): 30–37, DOI: 10.1159/000500373.

Pradhan, B.; Kjellstrom, T.; Atar, D.; Sharma, P.; Kayastha, B.; Bhandari, G.; Pradhan, P. K. (2019). "Heat stress impacts on cardiac mortality in nepali migrant workers in Qatar", *Cardiology, 143*, 37–48, DOI: 10.1159/000500853.

Rodahl, K. (1989). *The Physiology of Work*. London: Taylor & Francis Ltd.

Sławińska, M. 2020. "*The Method of Ergonomic Design of Technological Devices*", W. Karwowski et al. (Eds.): AHFE 2019, AISC 971, pp. 330–339. Springer Nature Switzerland AG.

Tanaka, H.; Monahan, K. D.; Seals, D. R. (2001). "Age-predicted maximal heart rate revisited", *Journal of the American College of Cardiology, 37* (1).

van den Bemt, B. J. F.; Gettings, L.; Domanska, B.; Bruggraber, R.; Mountian, I; Kristensen, L. E. (2019). "A portfolio of biologic self-injection devices in rheumatology: how patient involvement in device design can improve treatment experience", *Drug Delivery, 26* (1), 384–392, Taylor & Francis Group.

Yang. Y.; Chan, A. P. C. (2001). "Role of work uniform in alleviating perceptual strain among construction workers", *Industrial Health, 55*, 76-86.

Yuniarti; Zubaidi, T.; Santoso, P. (2005). "Uji Aplikasi Alat Bantu dan Pengering Sederhana dalam Industri Pengolahan Emping Melinjo Skala Rumah Tangga", *Jurnal Pengkajian dan Pengembangan Teknologi Pertanian, 8* (1), 137-149 DOI: 10.21082/jpptp.v8n1.2005.p%p.

Wesdock, J. C.; Donoghue, A. M. (2019). "Life-threatening heat-related illness with severe hyponatremia in an aluminum smelter worker", *American Journal on Industrial Medicine, 62*, 1068–1075.

Wiggermann, N.; Bradtmiller, B.; Bunnell, S.; Hildebrand, C.; Archibeque, J.; Ebert, S., Reed, M. P.; Jones, M. L. H. (2019). "Anthropometric dimensions of individuals with high body mass index", *Human Factors, 61* (8), 1277-1296. DOI: 10.1177/0018720819839809.