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Evaporation Analysis in Mushroom Cultivation Houses as an e-Module Supplementary Material to Enhance High School Students' Understanding of Physics Concepts

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Abstract: In majority, cultivation of oyster mushroom is carried out indoors, that the room was generally mentioned as mushroom cultivation house. One of physics concept that play a big role is evaporation. Evaporation itself known as a complex process that involves many physical quantities. It has been observed that in several schools in Jember, the explanations about evaporation, as one of discussion inside the unit of temperature and heat, were still non-contextual and tended to be incomprehensible. This research aimed to describe the physics concept of evaporation that applied inside mushroom cultivation house, then design a supplementary e-module based the analysis as physics learning material. To measure the evaporation values that occur inside mushroom cultivation house, FAO-Penman Monteith evapotranspiration formula was chosen. For the supplementary e-module that has been designed, here is also validated by experts.

Keywords: evaporation, mushroom cultivation house, oyster mushroom, and temperature and heat.

Abstrak: *Umumnya, budidaya jamur tiram ini dilakukan dalam ruangan semi tertutup, yang mana ruangan tersebut dikenal sebagai rumah budidaya jamur. Di antara konsep yang memainkan peranan cukup penting dalam hal ini adalah evaporasi. Evaporasi diartikan sebagai proses kompleks yang melibatkan sejumlah besaran fisis. Berdasarkan observasi yang telah dilakukan pada beberapa sekolah di Jember, penjelasan mengenai evaporasi , sebagai salah satu pembahasan di dalam bab suhu dan kalor, masih tidak kontekstual serta cenderung kurang komprehensif. Peneitian ini bertujuan untuk mendeskripsikan keberlakuan konsep fisika evaporasi yang pada rumah budidaya jamur, untuk kemudian mendesain suplemen bahan ajar berdasarkan analisis yang telah dilakukan sebelumnya sebagai materi belajar fisika. Dalam mengukur nilai evaporasi yang terjadi pada rumah budidaya jamur, digunakan fomulasi evapotranspirasi FAO-Penman Monteith. Untuk suplemen e-modul yang dirancang telah dilakukan validasi oleh beberapa ahli.*

Kata kunci: *evaporasi, rumah budidaya jamur, jamur tiram, suhu dan kalor.*

▪ INTRODUCTION

Indonesia is an agricultural country that has very diverse agricultural commodities. One of them is in horticultural commodities, which are currently starting to be in demand and popular, namely oyster mushrooms (Kusrini, Sulistiawati, & Imelda, 2019). To obtain good quality, the temperature and humidity conditions of the room where oyster mushrooms are cultivated must be at a value of 18-30 and 65%-85%, respectively (Najmurrokhman et al., 2020), carbon dioxyde concentration, and temperature is the most dominant environmental factor (Chang and Miles, 1989 in Han et al, 2009).

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One of the physical phenomena that occurs in mushroom cultivation houses is evaporation (Kurtzmann, 2010). Evaporation is a process of changing the phase of a substance from liquid to gas without boiling or at temperatures below its boiling point (Tipler, 1998). Evaporation rate increases with increasing temperature, surface area, and wind speed; and decreases with increasing air humidity, pressure, and liquid boiling point (Bond, 2013). In the phenomenon of evaporation that occurs in water contained in the soil or on the surface of the soil, the evapotranspiration framework is used. Evapotranspiration is basically a combination of the process of losing water from a land to the atmosphere through two processes, namely evaporation and transpiration (Huffman, 2013). One of the calculations that is standardized and has high accuracy with a correlation level reaching 0.93 to the results of measurements using a Lysimeter, so that it is commonly used to calculate the amount of evaporation in various studies is the FAO-Penman Monteith Method (Food and Agriculture Organization, 2012).

In learning physics, students' initial knowledge from the surrounding environment plays an important role as a basis for constructing an understanding of the material being studied (Hodson, 2014). The author observes that in several textbooks, the evaporation sub-material which is part of the material on temperature and heat for class XI SMA, is only briefly explained with concrete examples which are still very limited. Meanwhile, the phenomenon of evaporation itself can be found in various places and situations in everyday life without much awareness, and evaporation even plays an important role in activities carried out by humans, one of which is in cultivating mushroom plants which are carried out in mushroom houses.

As described in regulation of the minister of national education (Permendiknas No 11, 2005) states that in achieving national education goals, in addition to using textbooks as a mandatory reference, teachers can also use enrichment books in the learning process and encourage students to read them to add knowledge and insight. E-module supplements with a contextual approach are additional electronic (non-printed) learning media that contain study instructions, material, sample questions, conclusions, and practice questions for students to find/gain knowledge of the material being studied that is linked to real student lives. , so students can know, connect and apply competencies or learning outcomes that have been carried out in everyday life (Lestari, 2019). By supplementing contextual e-modules with real examples in everyday life, students will feel that the material being studied is important, and will gain a deep meaning for what they are learning (Rochsun & Agustin, 2020).

Departing from the conditions as described, further research was carried out on the analysis of the concept of evaporation in mushroom cultivation houses as a reinforcement of physics understanding through the design of e-module supplements. The purpose of this study is to describe the results of the analysis of physics concepts related to evaporation in mushroom cultivation houses and to design an e-module supplement regarding evaporation within the framework of the subject matter of temperature and heat based on the results of the analysis that has been carried out.

▪ METHOD

Participants

This study involved parties including researchers, mushroom farmers and 3 expert validators. Mushroom farmer is a person who cultivates oyster mushrooms, in which the cultivation activity is carried out. The validators consisted of 2 lecturers from Jember University Physics Education and a physics subject teacher; plays a role in assessing and validating the e-module supplement design that is made.

Study design and procedures

This study uses a descriptive research design. Descriptive research is defined as a research method used to describe existing phenomena as accurately as possible. The phenomena observed in descriptive research are readily available. Descriptive research can involve quantitative or/and qualitative analysis (Atmowardoyo, 2018). This research was carried out for 10 days at a mushroom cultivation house located in Rambigundam Village, Rambi Puji District, Jember in July – August 2021.

There were several stages in completing the research. To begin with, preliminary observations are made. The initial observation stage was to determine the research location, analyze the research location by looking at the operational conditions of the mushroom cultivation house. At the implementation stage, the data needed by the researcher will be obtained. At the data collection stage, measurements of temperature, humidity, solar radiation, pressure and wind speed will be carried out in the mushroom cultivation house. After the data is obtained, the next step is to analyze the measurement results that have been obtained to answer the problem formulation. The data obtained will be processed by comparing with the theory in the literature that has been included, so that arguments will be obtained from the results of the research conducted and can be used as a reference for compiling contextual e-module supplements. Teaching material supplements will be designed in the form of contextual electronic teaching material supplements by providing examples, illustrations, and questions related to real examples, namely evaporation in mushroom cultivation houses for temperature and heat materials. In the final stage, the designed module is assessed. An assessment module that shows the feasibility of the content and construct of a product used. Content feasibility is a component where what is developed has novelty and is in accordance with curriculum developments. Construct feasibility is based on the suitability of the theory contained in the material, measured based on assessment items. Module validation is based on expert judgment and the instrument used is a validation sheet.

Instruments

In this study, the instruments used were data tables containing temperature, humidity, solar radiation, and wind speed in mushroom cultivation houses and validation for the e-module supplement design. In the data collection instrument to reveal the evaporation value in the mushroom cultivation house, the FAO-Penman Monteith formula for evapotranspiration was used, which was chosen because it was standardized by the Food and Agriculture Organization of the United Nations and has often been used in previous studies to calculate evaporation that occurs on the soil surface and vegetation.

Data Analysis

After the data is obtained, the next step is to analyze the measurement results that have been obtained to answer the problem formulation. This study uses descriptive data analysis with quantitative and qualitative techniques. The data analysis process was carried out by examining all available data from various sources, including through observation, interviews, field notes, and documents. Data on temperature, humidity, air pressure, wind speed, area and light intensity that have been collected will then be processed using a formula related to evaporation, so that the evaporation rate is obtained through automatic calculations using Microsoft Excel. The data that has been processed is then used as a basis for explaining evaporation in the mushroom cultivation house in the e-module supplement.

Expert validation is a validation of the contents of the e-module supplement that has been made. Validators can assess, provide opinions, criticisms and suggestions for improving the developed module. Quantitative analysis is used in the validation data analysis technique obtained from expert validation sheets in the form of an average value. Data analysis results in the validation stage are categorized as in Table 1 below:

Table 1. Criteria for the average assessment of learning device validation

Validity Score V_a	**Validity Criteria**
$V_a \geq 3.20$	Very valid
$2{,}40 < V_a \leq 3{,}20$	Valid
$1{,}60 < V_a \leq 2{,}40$	Quite valid
$0{,}80 < V_a \leq 1{,}60$	Not valid
$0{,}80 \leq V_a$	Invalid

▪ RESULT AND DISSCUSSION

Evaporation is basically the process of transitioning substances from the liquid phase to vapor that occurs due to input energy so that in a certain amount it is able to break the intermolecular bonds which will then push the molecules which were initially tightly bound together to form a liquid, towards the air in the atmosphere. on it. Evaporation that occurs at the soil surface is a complex process that involves various physical quantities. The physical quantities of evaporation that were directly collected in this study included daily temperature and humidity, as well as the volume of water used for watering the mushroom house.

The evaporation concept studied in mushroom cultivation houses includes the relationship between physical quantities related to climate such as temperature and humidity on the daily evaporation of mushroom cultivation houses. The emphasis on the analysis of the two data is based on the assumption that the temperature and humidity data naturally tend to vary over time, as well as the availability of tools that can be accessed to retrieve the data. The data can be seen in Table 2 below.

Table 2. Daily temperature and humidity observation data

Day		1	2	3	4	5	6	7	8	9	10
Temperature (°C)	T_{maks}	31	31	32	32	31	32	32	32	32	32
	T_{min}	23	22	22	20	21	22	23	23	23	22
Relative humidity (%)	RH_{maks}	95	97	95	93	97	91	90	90	89	90
	RH_{min}	70	70	71	70	72	68	64	65	65	66
Wind velocity (m/s)		5									
Sun Radiation (MJ/m^2/hari)		19.19									

To retrieve daily temperature and humidity data, a digital thermometer is used with a memory card that can record minimum and maximum temperatures automatically for every 24 hours. As for the data on wind speed and solar radiation, the researchers did not take it directly, but sourced it from online weather stations. The selection of these data to be taken is based on a literature review which states that the data concerned are factors that affect the amount of evaporation on the surface of the substance.

There are many mathematical formulations for calculating the rate of evaporation, these differences depend on the conditions that occur in the area under review. In water-saturated soil conditions, the amount of evaporation tends to be the same as the open water surface. Meanwhile, when the water level drops below the ground surface, the evaporation rate will decrease significantly. In the phenomenon of evaporation that occurs in water contained in the soil or on the surface of the soil, the evapotranspiration framework is used. Evapotranspiration is basically a combination of the process of losing water from a land to the atmosphere through two processes, namely evaporation and transpiration (Huffman, 2013). Transpiration itself is evaporation that comes from plants as a result of respiration and photosynthesis. Transpiration is an important physiological process that affects the main character qualities of fresh mushrooms, such as weight, appearance, and texture (Mahajan et al., 2007).

One of the calculations that is standardized and has high accuracy with a correlation level reaching 0.93 to the results of measurements using a Lysimeter, so that it is commonly used to calculate the amount of evaporation in various studies is the FAO-Penman Monteith method which is mathematically formulated as follows.

$$ET_0 = \frac{0{,}408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0{,}34u_2)}$$

The rate of evapotranspiration is generally expressed in millimeters (mm) per unit time. The speed represents the amount of water evaporating from the surface of the soil and plants in units of water depth. The unit of time can be hourly, day, month or even the whole growth period or year. Since one hectare has a surface of 10000 m2 and 1 mm equals 0.001 m, the evaporation of 1 mm of water corresponds to the evaporation of 10 m3 per hectare. In other words, 1 mm/day equals 10 m3/ ha/day. From the data in table 2, after adjusting to the formula for calculating the amount of evaporation at the soil surface, using the evapotranspiration framework according to FAO-Penman Moenteith, the results are as follows.

Table 3. Evaporation calculation data

Day	Month	Date	$T_{average}$ (°C)	RH_{min} (%)	RH_{max} (%)	Actual Vapor Pressure (kPa)	Sun Radiation (MJ/m^2/day)	Evapotranspiration (mm/day)
1	6	26	27	70	95	2.90689	12.35654	8.790562793
2		27	26.5	70	97	2.854714	12.32135	8.724173431
3		28	27	71	95	2.943813	12.39227	8.85989099
4		29	26	70	93	2.751472	12.23467	9.199238864

5		30	30	72	97	2.823531	12.30860	8.5771046
6		1	27	68	91	2.819612	12.27255	9.406652579
7		2	27.5	64	90	2.785775	12.2238	9.817835308
8	7	3	27.5	65	90	2.809549	12.24894	9.7117139246
9		4	27.5	65	89	2.795502	12.23623	9.777511894
10		5	27	66	90	2.758845	12.21710	9.675440259

The table shows the variations in temperature and humidity each day. Each row in the table represents data retrieval every 24 hours. There are 10 rows in the table indicating that the data was taken for 10 days. Data collection was carried out at the end of June to be precise, starting on June 26 2021, until the beginning of July, July 5 2021 to be precise. From the results of the data calculations shown in the table, if calculated and rounded to two decimal places, the average evapotranspiration that occurs every day is 9.25 mm/day. The final relationship is, the greater the daily maximum temperature, the greater the evapotranspiration value. Then, the greater the minimum temperature, the smaller the evapotranspiration value. For the average temperature, the relationship with the final evapotranspiration value is that the greater the daily average temperature, the lower the evapotranspiration value. Within the framework of this FAO-Penman Monteith calculation, the relationship between temperature and evapotranspiration is not directly proportional. However, more specifically, what is linearly related to evapotranspiration is the daily maximum temperature.

Furthermore, for relative humidity, the data is the maximum RH and minimum RH. The amount of relative humidity affects the actual vapor pressure as given by equation 2.28, where the relationship is inversely proportional. Furthermore, the greater the value of the actual vapor pressure, the greater the evapotranspiration. Then the effect of relative humidity on the amount or rate of evaporation is inversely proportional. The greater the humidity of the air above the soil surface, the smaller the evapotranspiration.

Apart from collecting data inside, observations of temperature and humidity outside the mushroom cultivation house were also carried out. Among the reasons for selecting the observation time, it was based on indications of the application of treatment to the mushroom cultivation house either naturally or intentionally by mushroom farmers at that time. At 6 and 11.30 am used as a reference in which no treatment was given to the previous mushroom cultivation house, while at 17.00, watering was carried out at the mushroom cultivation barn. Observational data are presented in Figures 1 and 2 below.

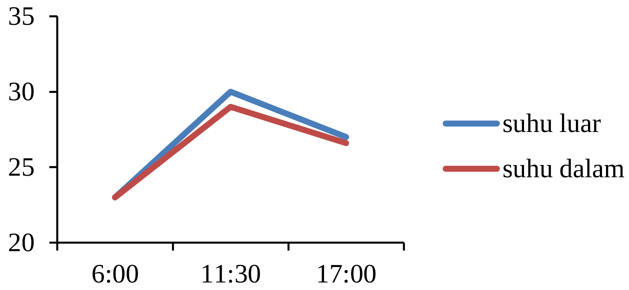

Figure 1. Comparison of Temperature inside and outside the mushroom cultivation house

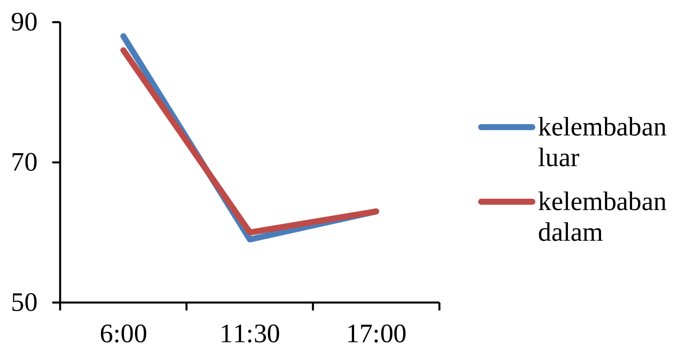

Figure 2. Comparison of the relative humidity inside and outside the mushroom cultivation house

Based on the figure, the temperature and humidity inside and outside the mushroom cultivation house seem to coincide which means that the difference is slight, so it can be concluded that ambient temperature and humidity greatly affect the temperature and humidity in the mushroom cultivation house, and watering causes the temperature of the mushroom cultivation house to drop be lower than that of the surrounding area. Regarding the amount of heat required to trigger evaporation, in this case it is viewed through the enthalpy of evaporation, which is expressed mathematically in the following equation.

$$q = m.\Delta H_{vap}$$

In the research that has been done, the mass taken for this calculation is the mass of water used to water the mushroom house. Watering is carried out using 40 liters of water, and because the density of water is 1000 kg/m3 , the mass of water used is 40 kg. Then for the enthalpy of evaporation of water at 25 degrees Celsius is 2441.7 kJ/kg. So based on calculations, it is obtained that the amount of heat energy needed to evaporate the water used in the watering process is 97668 kJ. As for the water content received by the mushroom cultivation house every day, of course it does not only come from watering, but from environmental factors, namely the weather at that time, especially precipitation. However, because the mushroom cultivation house is a semi-enclosed building, where the soil that is shaded by the roof of the mushroom cultivation house does not directly receive rain or dew, in this case this factor is ignored. The calorific value states the amount of minimum energy required to evaporate water after the watering process every day.

Based on the conversion factors for evapotranspiration according to the Food and Agriculture Organization, which for water with a temperature of 25.1 mm/day the evapotranspiration is equivalent to 2.44 MJ/m2 / day, the average evapotranspiration is 9.25 mm/day which is obtained from research data, equivalent to 22.57 MJ/m2/day. Regarding the cultivation constraints in the mushroom houses studied, through interviews conducted by researchers with mushroom farmers, it was found that so far, the constraints experienced were that the climate tended to be too humid. Mushroom cultivation places where the humidity is too high will affect the growth and development of mushroom plants, where the mushrooms will have a high moisture content or be wet. Mushrooms with high water content are not in demand in the market. Based on research data, the average relative humidity in daily mushroom houses is 80.4%. If it is reviewed based on the literature review, the optimal humidity requirement for mushroom growth is 80-90%, then the humidity of the mushroom house at the time of research actually meets this range. Farmers also said that at another mushroom house located in Kasian, Puger experienced higher humidity problems, due to insufficient ventilation. Regarding ventilation as air circulation holes, if it is related to the concept of evaporation, the more ventilation, it will be able to increase evaporation in mushroom cultivation houses because evaporation increases with increasing wind speed.

The data that has been obtained from the results of the evaporation concept analysis are used as material in compiling materials, sample questions, conclusions, and practice questions on the design of electronic module supplements (e-modules) within the framework of the subject matter of temperature and heat. By analyzing the physical quantities involved and the role of evaporation events in mushroom cultivation houses, students are expected to be able to understand the utilization and physical review of the phenomenon of evaporation in mushroom cultivation houses.

Figure 3. Cover design of the physics e-module supplement

The physics e-module supplement is intended for high school students in class XI IPA, where in the Revised 2013 Curriculum at that grade level there is material about temperature and heat. The subject matter contained in the e-module supplement is described through 2 learning activities. The first learning activity contains material, sample questions, and practice questions regarding temperature, heat, and heat transfer universally or have not focused on application in mushroom cultivation houses. As for the second learning activity, it contains material, sample questions, and practice questions regarding changes in the state of matter and the application of evaporation in mushroom cultivation houses. The material presented is quite concise so that students are more than happy to read it and easily understand the contents of the e-module supplement.

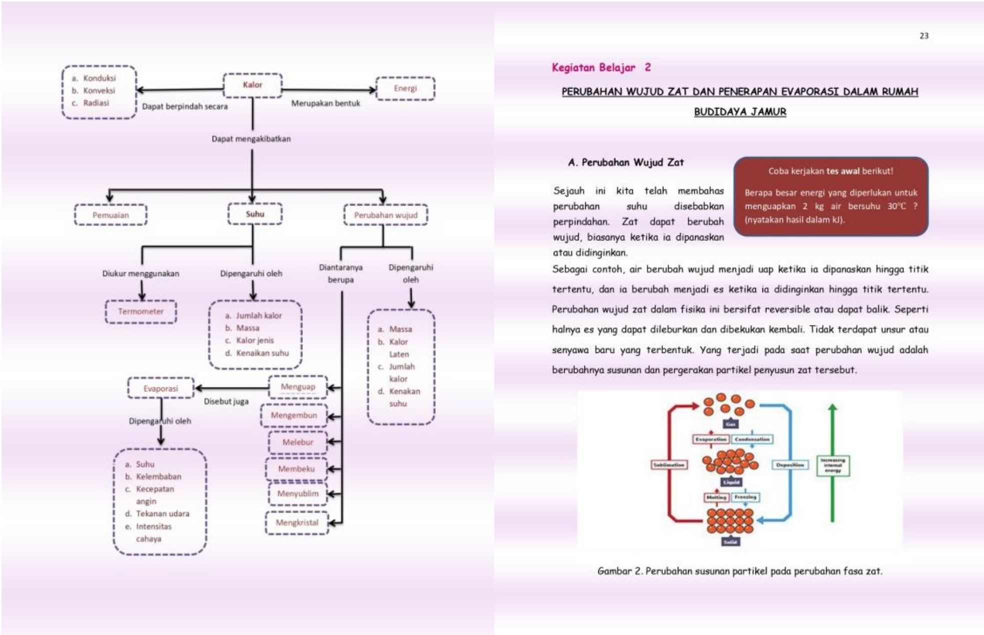

Figure 4. The distribution of learning activities in the e-module supplement design

In order to support competency achievement, in addition to learning materials, in each learning activity pre-tests, examples of contextual questions and their discussion, discussions, and practice questions are also presented at the end of learning activities. To find out the feasibility of this e-module supplement design, a validation process was carried out. The validators consisted of 2 lecturers from the Physics Education Study Program at the University of Jember, and 1 physics teacher from SMAN Balung. The final average validation score obtained was 3.29. Referring to the categorization in the literature used, the validation results show that the e-module supplement design is very valid.

▪ CONCLUSION

Several physics concepts related to evaporation that apply to mushroom cultivation houses, namely evaporation occurs as a process of releasing water vapor molecules from the soil surface into the air in the mushroom house with a daily average of 9.25 mm/day during the 10 day study period, which are influenced by factors ambient temperature and humidity. The effect of temperature on evaporation rate is linear, while the effect of relative humidity on evaporation is inversely proportional. The concept of wind speed is involved in providing ventilation in mushroom cultivation houses, the effect of which is linear. The energy involved in the evaporation phase transition process is the latent heat or enthalpy of evaporation, with the amount needed to evaporate the entire mass of water used in watering is 97668 kJ. The results of the analysis of physics concepts related to evaporation in mushroom cultivation houses are then abstracted and used as a supplement e-module design for class XI IPA high school students within the framework of the subject matter of temperature and heat. Consisting of materials, sample questions, summaries and practice questions on temperature, heat, heat transfer, shape changes, and evaporation and their physical application in the Rambipuji mushroom cultivation house, the e-module supplement has been validated with a validity score of 3.29.

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