HUMAN ENERGY COST OF SELECTED FARMSTEAD TASKS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY

Robert Dean Fox

1958

HUMAN ENERGY COST OF SELECTED FARMSTEAD TASKS

By

Robert Dean Fox

A THESIS

Submitted to the College of Agriculture
Michigan State University of Agriculture and
Applied Science in partial fulfillment of
the requirements for the degree of

MASTER OF SCIENCE

Department of Agricultural Engineering

1958

Approved by Merle L Esmay

ACKNOWLEDGEMENTS

The author expresses his sincere gratitude to Dr. Merle L. Esmay of the Agricultural Engineering Department, for his guidance and many helpful suggestions during the course of this study.

The author feels deeply indebted to Dr. A.W Farrall, Head of the Agricultural Engineering Department, for making possible the research assistantship for this study.

The author is very grateful to the North Central Research Committee, NC 23, on farm buildings, who provided the Agricultural Engineering Department with the funds for this study.

The author also wishes to thank the individuals who acted as subjects in executing the tests. They were: subject 1 - Ed Wilkie, subject 2 - Ed Fox, and subject 3 - Mel Gomulinski.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Mechanization of farmyard operations has lagged far behind the use of machinery in field operations. One reason for this lag is that no direct and convenient method of justifying the purchase of materials-handling equipment is being used. In the past the farm operator's personal opinion of the convenience of the equipment and the time saved by using the equipment have been the usual basis for purchase. There is a definite need for a method of objectively determining the practicability of using such equipment.

The human energy cost of doing a job is a method of objectively determining the need for mechanizing that job. Human energy requirements can be employed in selecting and designing the equipment best suited for a particular job. Energy expenditure data can also be used in planning building layouts, work procedures and techniques.

This study was conducted to measure the amount of human energy required to hand pitch silage from an upright silo. This research problem was also designed as a pilot study to develop techniques and procedures for further energy measurement studies to be conducted outside the laboratory.

Oxygen is a measure of energy

The human body is much like an engine, it must use fuel to remain animate. The fuels utilized by the body are chemical compounds which are oxidized to give the body energy. They combine chemically with oxygen in the oxidation process. Therefore, the amount of energy used by the body can be determined by measuring the oxygen consumed by the body. In this study the expired air was metered and its oxygen content measured to ascertain the oxygen used by the body.

The body fuels depend on the diet of the person and other physiological factors, however for this study these elements were considered to vary an insignificant amount as compared to some other uncontrollable variables.

Work energy

In this study the work energy requirements were found by subtracting the energy required for standing at rest from the energy required to do the work. The position of standing at rest was chosen as a basal rate because it is the normal position for a farmer when working and it has been used as a basis for several other energy studies of similar nature (6,27).

Tests

There are two types of oxygen collection procedures which are used to measure the oxygen consumed by the body while doing work. The steady state method can be used for exercise that reaches a constant oxygen consumption rate. The test is started after the oxygen intake rate becomes stable and stops before the end of the exercise.

The integral method collects oxygen from before the exercise begins until the end of the recovery period. The latter type of test was used in this study because it can be used for tests of short duration, while the steady state test should have a pre-test exercise time of about ten minutes.

The tests were run under actual field conditions. This was made possible by the use of the light weight Kofranyi meter for metering and sampling the expired air. These field tests are an effort to obtain data on the expenditure of energy while working under the exact conditions that a farmer would encounter.

REVIEW OF LITERATURE

Physiological Background

Oxygen requirements

Morehouse and Miller (20) stated that the human body requires a continuous supply of oxygen to all tissues. Oxygen can not be stored in tissues so must be constantly supplied by the blood stream. The muscles require a greater amount of oxygen during exercise. The oxygen requirement of the body is determined largely by the characteristics of the exercise. Temperature and humidity also affect oxygen utilization.

Gould and Dye (14) stated that the additional call for oxygen is satisfied by a larger flow of blood to the muscles. This can be accomplished by diverting blood to the contracting muscles from less active regions or by increasing the volume of blood output by the heart.

Heart output

Heart output (20) is the product of two factors, stroke volume and heart rate. The increased blood flow during exercise is a result of an increase in both factors, but the relative increase in each factor depends on the nature of the exercise and the physical condition of the subject.

Indication of a subject's physical condition

According to Riedman (26), a slow pulse rate in the standing and reclining positions, and a small difference between the two are a sign of excellent physical condition. Normal pulse rate reclining is four to five beats per minute lower than when sitting; sitting is six to eight beats per minute lower than standing. A person in good physical condition will have a rise of less than ten beats per minute whereas a weak subject will show an increase of twenty to forty beats per minute when moving from the reclining to the standing position.

Factors affecting heart output

Accurate data (20) on the cardiac output in various types and intensities of exercise are not available. A great deal is known about the changes in heart rate which accompany exercise but little is known about the equally important adjustments in stroke volume.

The stroke volume (20) is affected by inadequate venous return. During light muscular work or rhythemic contractions such as running, the blood flow in the veins is stimulated by the moving muscles, however in heavy static work, such as weight lifting, the contractions of the muscles may hinder the venous return of blood to the heart.

Morehouse and Miller (20) related that several factors affect heart output. Some of them are:

1. The cardiac output is usually reduced when the subject stands; since pulse rate increases, that indicates a reduction in stroke volume.

2. The output of the heart is increased temporarily by eating.

3. Exposure to cold slows the heart rate but increases stroke volume, leaving cardiac output unchanged unless shivering occurs, which increases cardiac output.

4. Exposure to warmth increases resting output; the heart rate is increased with a slight reduction in stroke volume.

5. Emotion increases the heart rate at rest and during light exercise, but probably has little influence on the maximal heart rate.

6. The same is probably true, to a lessor degree, of an increase in environmental temperature and humidity.

7. Adverse conditions such as fatigue, lack of sleep, malnutrition and acute infections may reduce the maximal cardiac output capabilities of an individual.

8. Heart rate varies with age; decreasing from birth to middle age and increasing slightly in older people.

<u>Heart rate</u>

The use of heart rate as a measure of energy expenditure is a much debated subject. As can be seen from the above list, there are several variables which affect heart rate besides muscular activity. Most of the variables can be controlled by a suitable arrangement of tests and by choice of subjects.

Henderson and Haggard (15) stated that for light activities such as a walk at an easy pace, the chief compensation for the increase in blood flow is an increase in pulse rate. Beyond moderate exercise the stroke volume and oxygen utilization are involved along with a further increase in heart rate.

Gould and Dye (14) observed the stroke volume of non-athletic individuals to be nearly proportional to the blood flow during rest and exercise. However, in athletes, the stroke volume generally increased considerably, in some cases forty to fifty percent during exercise.

Ford and Hellerstein (12) in studies of industrial workers found poor correlation between heart rate changes and energy expenditure.

Morris (23) stated, "Heart rate is not satisfactory for estimating the physiological cost of work."

Karpovich (17) published a graph which showed the heart rate-work load relationship for four men while riding a bicycle ergometer with varying loads. These subjects had nearly linear relationships between pulse rate and work load up to a limiting load; 4,000 foot-pounds in one case and 8,000 foot-pounds in the other three cases. This curve was used as a basis for tests at North Carolina by Suggs and Splinter. They (29) used a strain gage fastened to the temple for measuring the pulse rate of the subjects and then converted to energy consumed by means of Karpovich's curve.

Oxygen intake

The oxygen intake for a worker at various levels of work has been shown (17) to be a direct relationship. Figure 1 shows the relationship between the oxygen intake and work on a bicycle ergo-

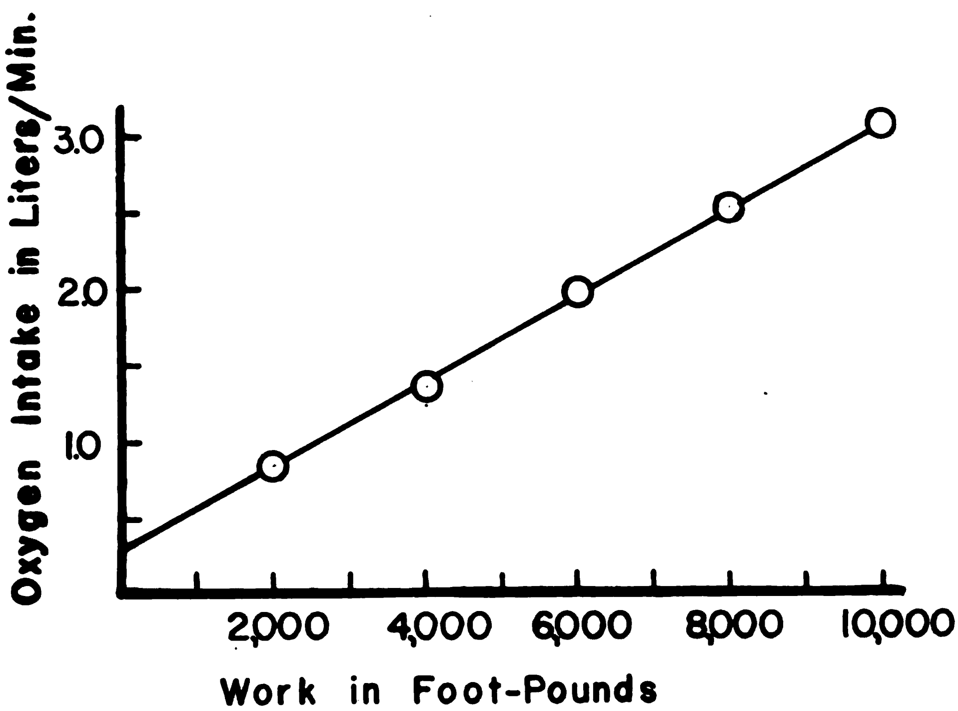

Figure I. Oxygen Intake-Work Relationship. From Reference 17..

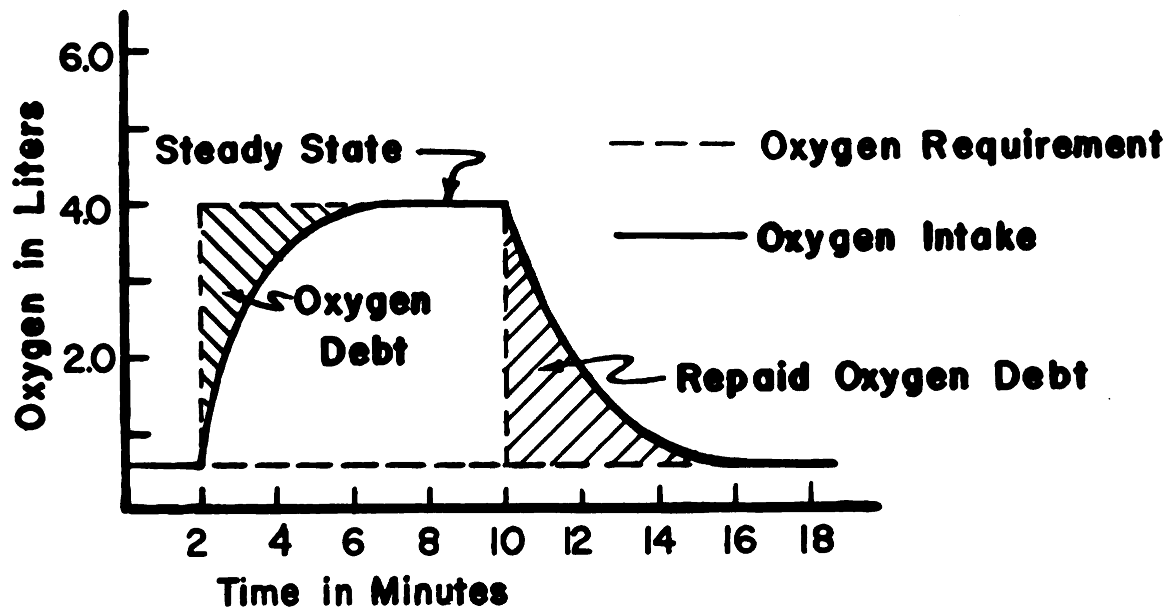

Figure 2. Oxygen Requirement & Intake During

Moderate Exercise. From Reference 13.

meter.

Karpovich (17) has found that the oxygen intake rate does not parallel the oxygen usage rate in the body. When muscular activity begins, there is not enough oxygen at the muscles, so anaerobic sources of energy are used to supplement aerobic sources which use the available oxygen. Those stores of anaerobic energy are limited and the body produces more energy by increasing the oxidation rate whenever possible. The anaerobic energy is measured by the oxygen that must be taken in to replace it. This delay in the supply of oxygen to convert fuels into energy is called oxygen debt.

<u>Steady state exercise</u>

Figure 2 (18) shows the time-oxygen relationship for moderate exercise. The oxygen requirement rises from the base level to the work level the instant work starts. The oxygen intake requires from two to five minutes to reach the usage level. The period where oxygen intake is equal to oxygen used is called the steady state work level.

There is a recovery period after the stopping of exercise when the oxygen debt is repaid. The length of the recovery period is dependent upon the intensity of exercise.

<u>Severe exercise</u>

There is a limit (14) to the amount of oxygen that can be supplied to the muscles. The limiting factor in the body is the ability of the blood stream to carry the oxygen. Therefore, if the intensity of exercise is too great, a steady state condition will never be reached and the oxygen debt will continue to increase until the muscles become exhausted. Figure 3 (13) is an example of this type of exercise.

Recovery period

After the stopping of exercise (17), the oxygen intake rate declines until the pre-exercise rate is reached. This fall in oxygen intake rate can not be measured easily, however, it has been found (18) that heart rate returns to normal much slower than oxygen intake rate (see figure 4). Thus heart rate can be used to estimate oxygen intake rate, for when heart rate returns to normal it is certain that oxygen intake rate will be back to normal.

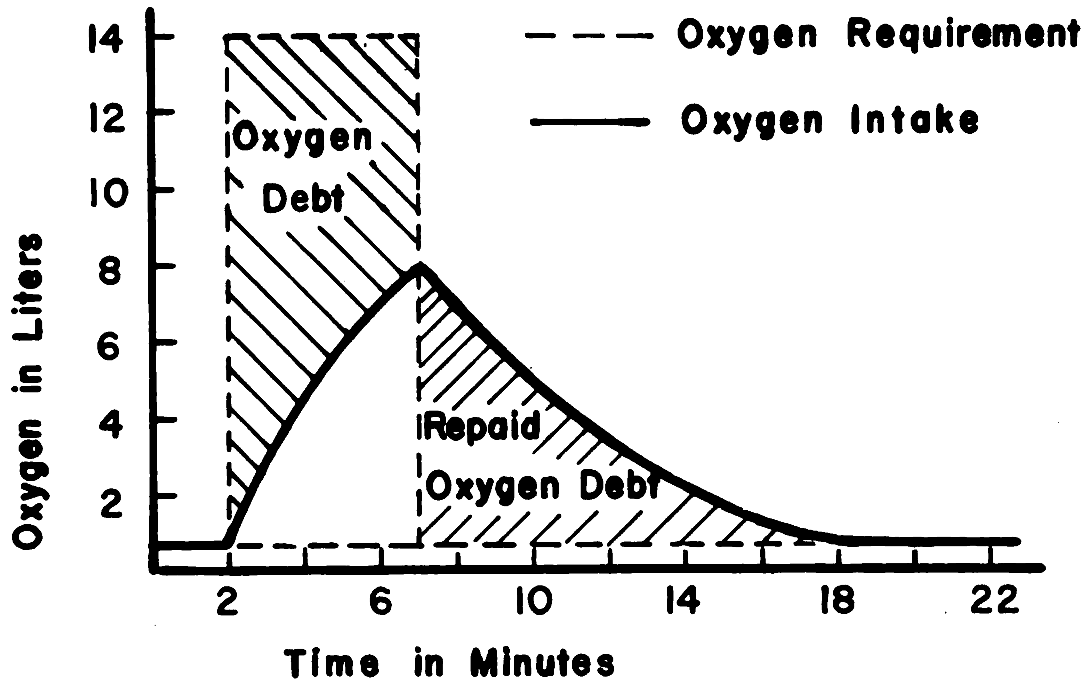

Figure 3. Oxygen Requirement & Intake During Severe Exercise. From Reference 13.

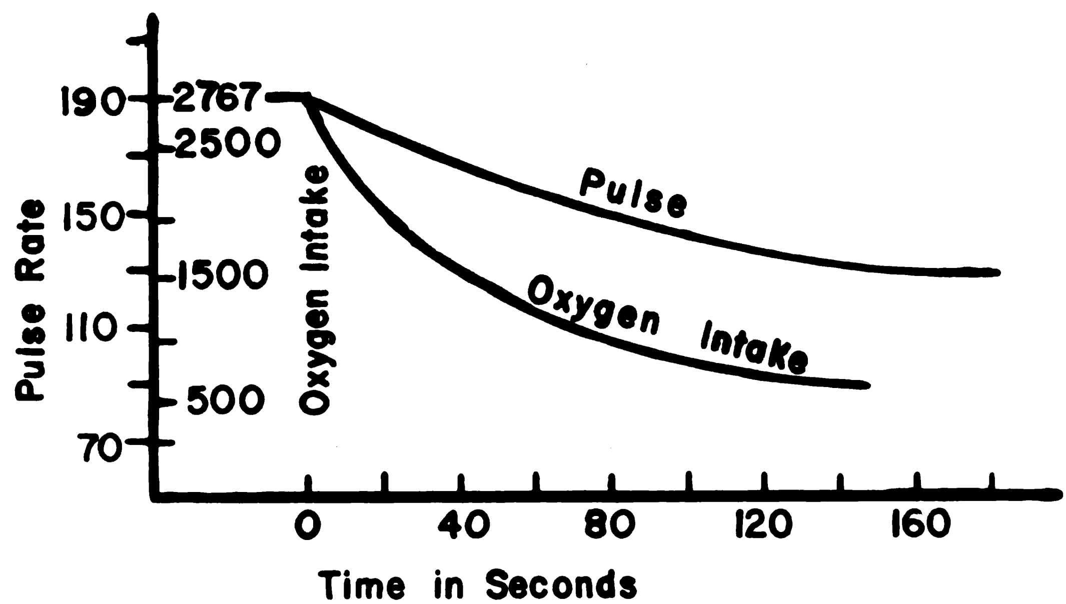

Figure 4. Recovery of Pulse and Oxygen-Intake Rates. From Reference 18.

Energy Studies

<u>Use in design</u>

Dupuis (11) found from energy measurement tests that the energy used in driving tractors could be reduced as much as 28.5% by alterations on a commercial design. He accomplished this by changing the location of the brake and clutch petals, reducing the operating force needed for these pedals, using a properly designed seat, moving hand operated levers within easy reach, and shortening the operating stroke of the levers.

Morris (21), in tests at Cornell, found that the time required to milk cows was equal for all milking platform heights. The energy used by the operator while milking a cow on the higher platforms was significantly less than the lower ones. The highest platform tested was 36 inches and it was the most efficient in energy consumption. This points out the value of energy measurement in addition to time studies as a tool in the evaluation of a work system.

Ross (27) used energy in analyzing the entire materials handling system of a farm. He divided the farmer's movements into short elements of constant energy consumption rate; then using energy rates from previous studies, the total energy used in each element was computed. The total energy used in any system was determined by summing the energy used by each of the elements in that system.

Energy studies can be used to select the best operating speeds. Suggs and Splinter (29) found that as machine speed increased, energy efficiency usually increased to a maximum and then declined. Their tobacco priming studies were conducted on subjects while walking and while riding on a low seat at three speeds. The greatest number of leaves were picked at the high speed but the greatest number of leaves per unit of work were picked at the intermediate speed. The results were: machine methods were three to four times as fast as hand methods, however, the optimum machine speed was fifteen times as efficient in energy consumption.

Because driving a tractor is a sitting operation, many people tend to think it is easy work. Physiological tests (11) have shown that manure loading with a tractor takes as much energy as cutting logs or carrying sacks of flour; near the limit of continuous human performance.

A study (23) of the daily activities of a group of farmers has shown energy expenditure to be twenty to thirty percent higher than was found for a group of industrial workers.

APPARATUS

Kofranyi Meter

Description

The Kofranyi meter is 10.1 inches high, 8 inches wide and 4.4 inches deep, (see figure 5). It, with the accessory collection equipment, weighs approximately 8 pounds. The meter is used to measure the volume of expired air and to take a sample of that air to be analyzed for oxygen percentage. The Kofranyi is a dry gas meter with several compartments which fill alternately. The gas flowing through the meter drives a series of gears which turn the recording dial. The gas flow also drives a small aliquoting pump which draws a sample of air from that passing through the meter and pumps it into an aliquot bladder. There is a thermometer in the meter box to measure the air temperature as it passes through the meter.

Calibration

The Kofranyi meter was calibrated to check the accuracy of the gas flow meter. Several Kofranyi meters had been calibrated at Michigan State University (19) and the method used in this study was similiar to their procedures. The air was evacuated from a Douglas bag, then air was pumped into the bag through a Precision-Wet-Test meter, and the volume pumped into the bag was recorded. The Douglas bag was always filled at a slow flow rate within the calibrated range of the Wet-Test meter. The air was pumped at

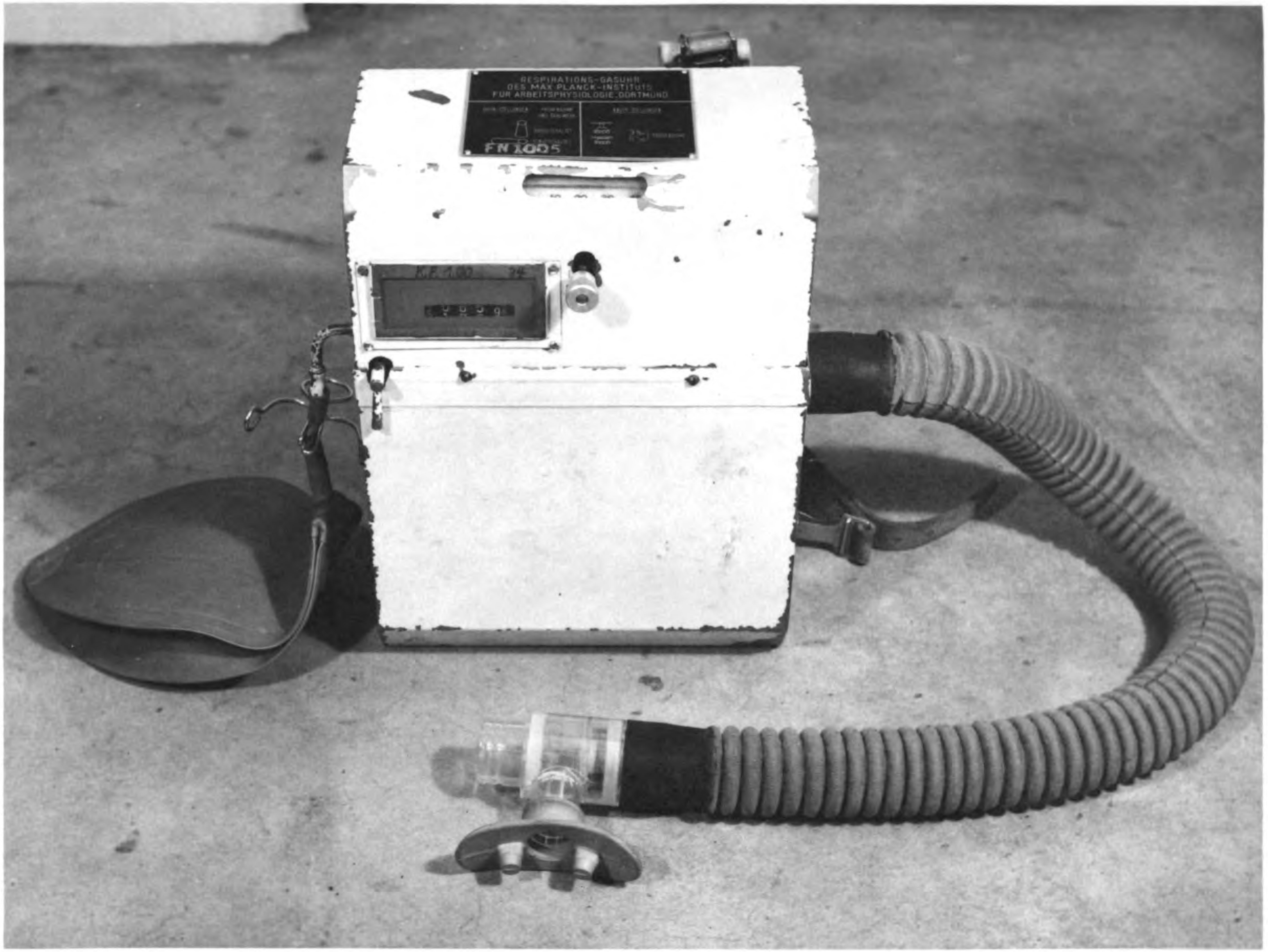

Figure 5. Kofranyi Meter

various flow rates from the Douglas bag through the Kofranyi meter, and the volume recorded. The actual flow rate was plotted against the Kofranyi recorded flow rate. This graph is shown as figure 6.

The steady rate air flow through the meter during calibration is not a duplication of actual test conditions. A person wearing the meter is spending about half the time inhaling and half the time exhaling, therefore, an average flow rate of fifteen liters per minute from a worker would mean about thirty liters per minute for half the time and none for the remainder. Figure 7 is a graphical representation of this conception.

The thermometer used in the meter was checked against a known accurate thermometer and was found to be accurate.

Use

The meter is very simple to operate and requires very little instruction before it can be worn. It is strapped to the back like a rucksack as shown in figures 8 and 9. Tests (16) have shown the energy cost of wearing the meter to be negligible.

There are two aliquot sample sizes which can be used, approximately 0.6% or 0.3% of the total air flow. When the aliquot sample size was 0.6% and the bladder became full, the meter read a lower volume than actual. The 0.3% sample size was used for all the tests in this study, because there seemed to be less back pressure against the expiring of air.

The meter was oiled once a week to insure a minimum of

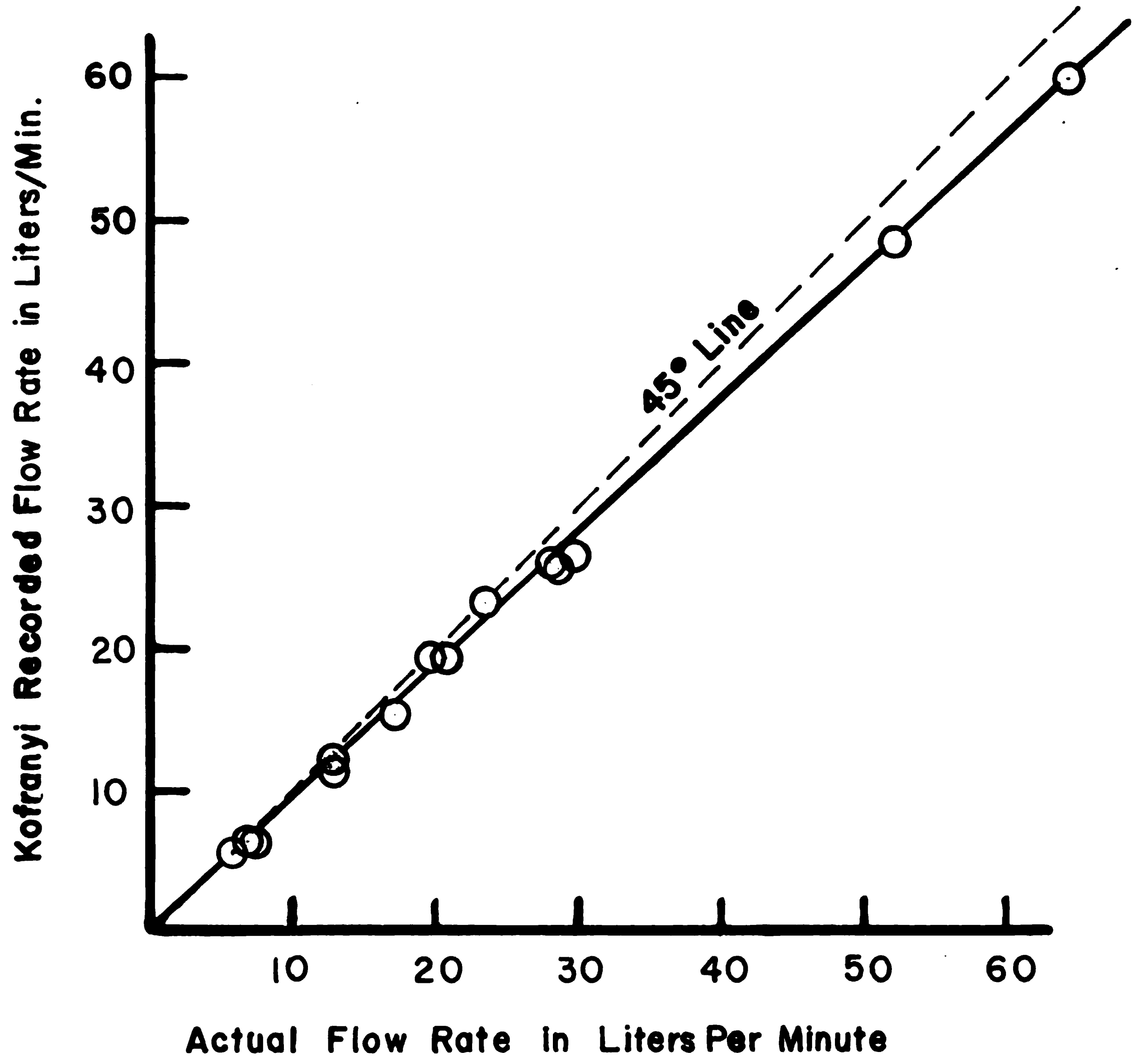

Figure 6. Calibration Curve for Kofranyi Meter No. FN-1005

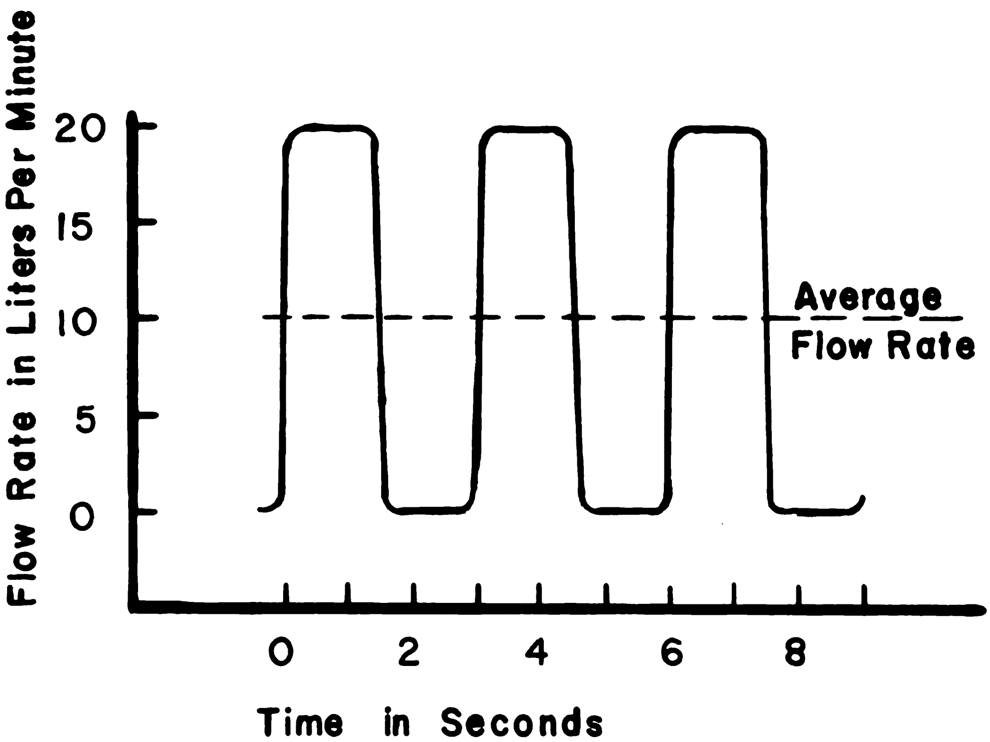

Figure 7. Expired Air Flow Rate

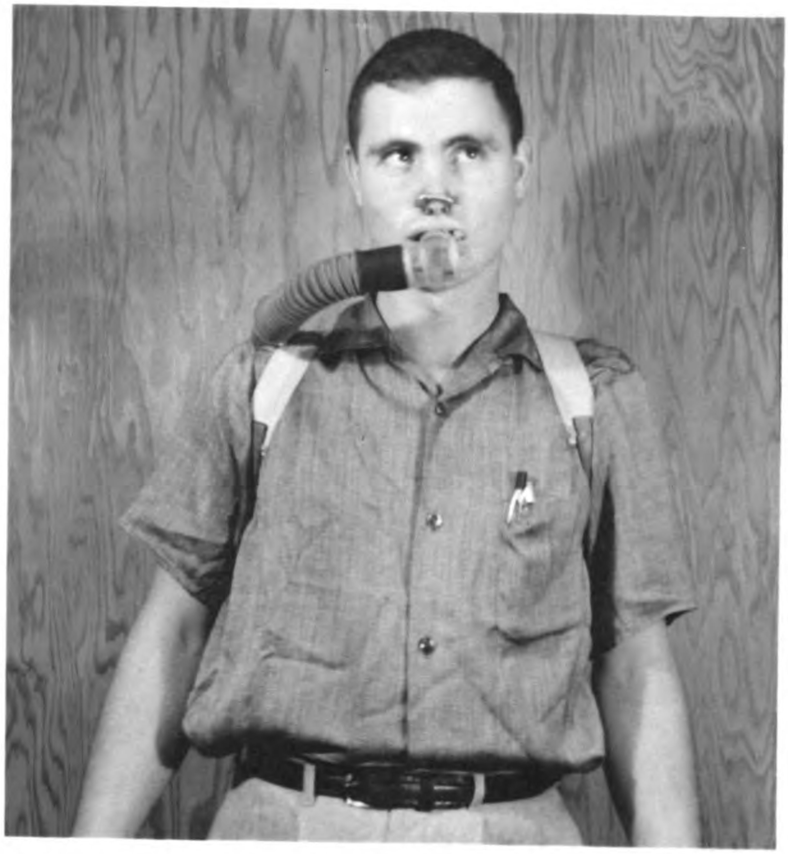

Figure 8. Front view of subject with Kofranyi meter in place

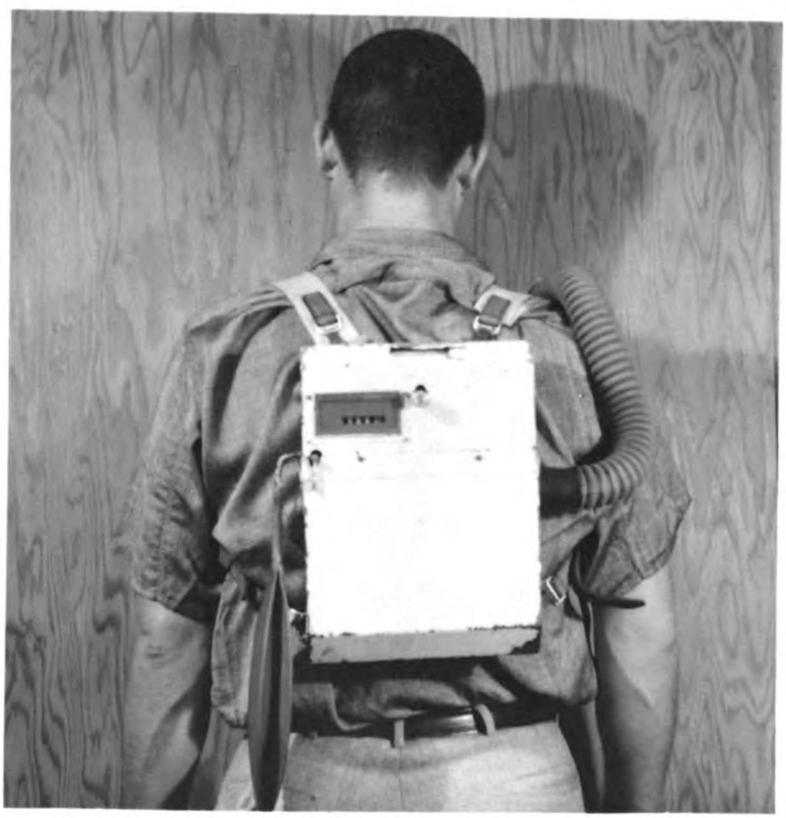

Figure 9. Back view of subject with Kofranyi meter in place

driving force. In cold weather the meter tended to run harder, requiring more effort for breathing. The meter collected moisture which had to be poured out of the inlet tube periodically.

Aliquot Bladders

The bladders used were of two sizes, 100 milliliters and 1,000 milliliters. They were constructed of rubber with grooves along the sides to reduce their tendency to spring to a shape when evacuated. There was a slight aspirating of air by the bladders when they were at low pressure.

The volume of the sample about to be taken should always be checked before the test is started, to insure adequate bladder size for the sample. If the bladder becomes full, its back pressure will get as large as that produced by the aliquot pump and no sample will be taken. The bladders were stored full of expired air when not in use to keep the walls saturated with carbon-dioxide, as carbon-dioxide has a very high diffusion rate through rubber.

Mouthpiece and Valve

The rubber mouthpiece fits into the mouth and has small flanges which can be bitten to secure the mouthpiece and valve (see figure 8). The plastic valve fastens to the mouthpiece. It has two mica discs with backup springs which permit the passage of air in one direction only. The air comes in from the outside and is expired through the tube to the meter when the wearer is breathing. It has a dead space of 32-41 ml. and is very light in weight, no support besides the mouthpiece is necessary.

Nose Clamp

The nose clamp used was a common swimming nose clamp.

Connecting Hose

The hose connecting the plastic valve to the meter was made of flexible rubber about one inch inside diameter. A clamp was placed on the right support strap of the meter to hold the hose in place during active exercise. The hose should be stored in a warm place to remove some of the moisture that condenses in it. The corrigations in the hose do not permit the moisture to be poured out.

Glass Syringes

The glass syringes used were thirty and fifty milliliters in capacity. They were used to store and transfer the expired air samples from the time of collection till they were analyzed. Tests (16) have shown that samples could be stored in glass syringes for up to 72 hours without affecting the composition of the sample.

The syringes were kept well sealed with stopcock grease. The best criterion for a good seal is that a portion of the plunger in contact with the cylinder be transparent in appearance. A frosted appearance indicates a poor seal.

The rubber tubing on the outlet end of the syringe was clamped with a screw clamp. A picture of the sample collection and storage equipment is shown in figure 10.

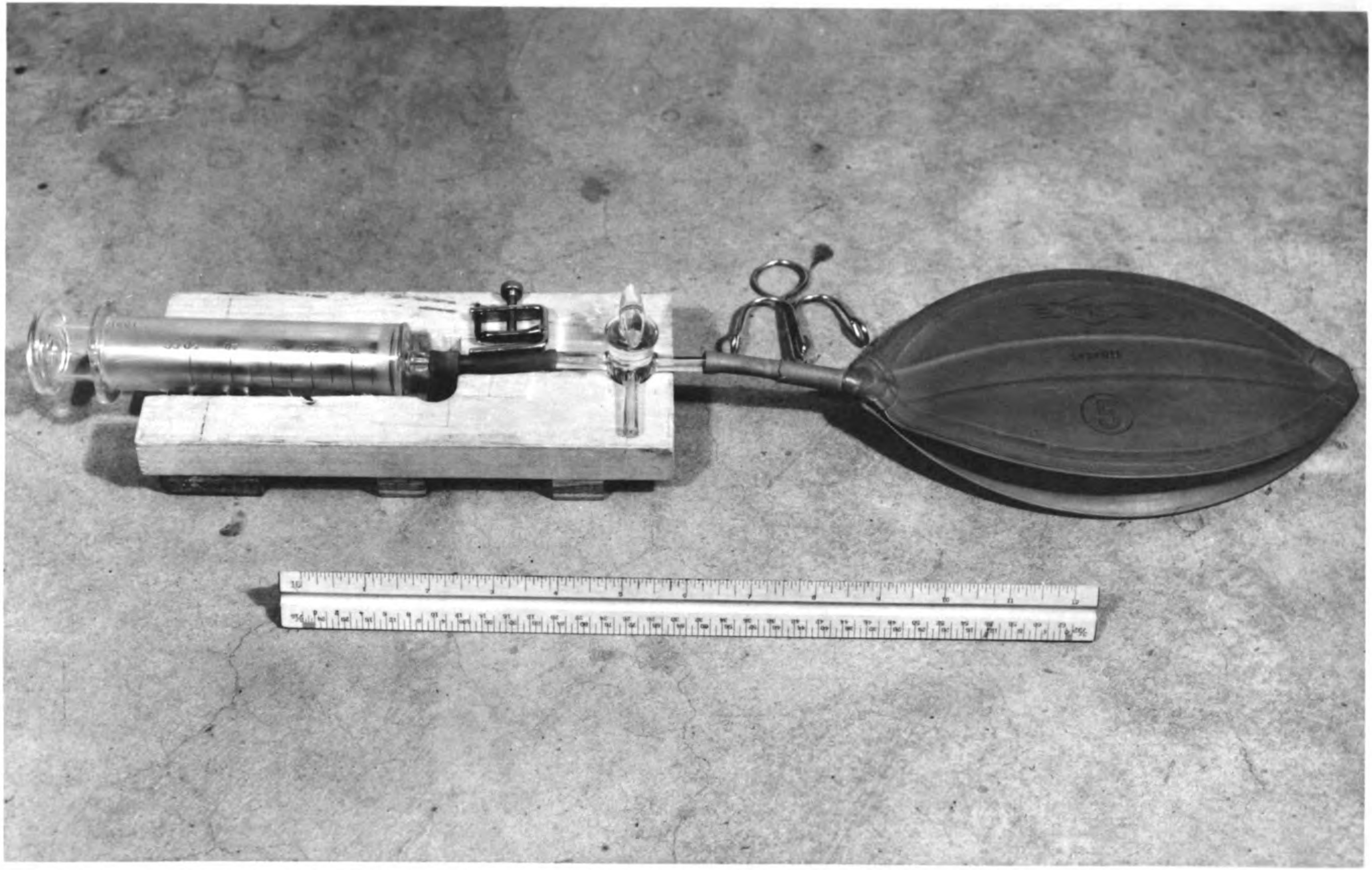

Figure 10. Sample collection and storage equipment

Beckman Oxygen Analyzer

Principle of operation

The model E2 Beckman oxygen analyzer is an instrument used to measure the oxygen percentage in a sample of gas. The E2 model has two ranges which can be used; one can measure oxygen percentages between zero and twenty-five, the other between sixteen and twenty-one.

The Beckman measures the magnetic susceptibility of a gas with a magnetic torsion balance. Oxygen is one of the very few gases which are strongly paramagnetic, therefore the amount of oxygen present in a sample of gas can be easily measured.

> The magnetic balance consists of a mirror attached to a dumbbell-shaped test body which is supported by a quartz fiber. The test body is subjected to a magnetic rotational force which is dependent upon the difference between the volume susceptibilities of the test body and the gas which the test body displaces and upon the physical constants of the instrument. Whenever the susceptibility of the gas changes, as a result of changing composition or pressure, the test body rotates.
> The test body is returned electrostatically to a null position by manually varying the voltage between the test body and the two reference vanes. The oxygen concentration in the analysis cell is read from the position of the potentiometer dial (called a Helipot Duodial) used to vary the voltage. A linear relationship exists between this voltage and the oxygen concentration. The test body is at its null position when the narrow light beam reflected from the mirror is centered on the vertical engraved line in the translucent scale. (3)

Calibration

There are two electrical adjustments necessary on the Beckman, the ZERO and the SPAN. The ZERO adjustment fixes the zero point of the linear scale and compensates for differences in the magnetic susceptibility of the background gases and for changes in the response characteristics of the analyzer. The ZERO calibration was accomplished by setting the Helipot Duodial on zero, setting the range selector on the 0 to 25% scale and turning the ZERO knob until the light beam is centered on the vertical black line when carbon-dioxide is placed in the analyzer.

A correction for the background gases was necessary because carbon-dioxide was used to calibrate instead of nitrogen. The correction factor was computed using the information in the manual (3), as follows:

The equivalent oxygen percent in the background gases is equal to the fraction of the sample which is CO_2 times the equivalent oxygen % of CO2 plus the fraction of the sample which is N_2 times the equivalent oxygen % of N_2. Assuming a R.Q. of 0.85 and an O_2% of 15%, we see:

For CO_2, .2776 x .626 = .08%

For N_2, .7224 x .385 = .26%

Total .34%

Equivalent oxygen percent in calibrated gas, CO_2:

.85 x .626 = .533%

The difference in equivalent oxygen percents is equal to -.19%. The correction is negative since the background gases are less diamagnetic than the calibrated gas. All the gas samples analyzed in this study were near enough to 15% that the correction factor of -0.19% can be applied to all analyzer readings to correct for background gases.

The SPAN adjustment was made using outside air as the reference gas. The Helipot dial was set at 20.93% oxygen and the light beam centered with the SPAN knob.

There was an additional correction made to the oxygen percentages read on the Beckman. This was necessary because the gas samples and the outside air were not dry when they were analyzed. This correction factor was found by subtracting the water vapor correction factor due to the water in the calibration outside air from the water vapor correction factor due to the expired samples. The correction factors for each of the elements was found from the formula, $\frac{Pt}{Pt - PH_2O}$ given in the analyzer manual (3). Pt is the total gas sample pressure in the analysis cell measured at the outlet nipple. PH_2O is the partial pressure of water vapor in the gas sample measured in mm. of mercury. This factor varied with the barometric pressure and with gas pressure, therefore, it was computed for each sample.

Use

The Beckman is a very simple instrument to use, however a few precautions were taken to insure proper operation.

a. The ZERO point was calibrated every week.

b. The SPAN was calibrated each time the analyzer was used.

c. The analyzer was allowed to warm up at least one-half hour before samples were analyzed.

d. A Sorensen & Co., Inc. model 500S a.c. voltage regulator was used to insure a steady voltage supply.

e. The vacuum pump oil level was checked occasionally.

f. The stopcocks and hose system was checked for air leaks.

g. The light beam source lamp has an expected life of approximately 15 hours, therefore it should be on only when readings are being made.

The gas flow circuit is shown in figure 11 and a picture of the oxygen analysis equipment is shown in figure 12.

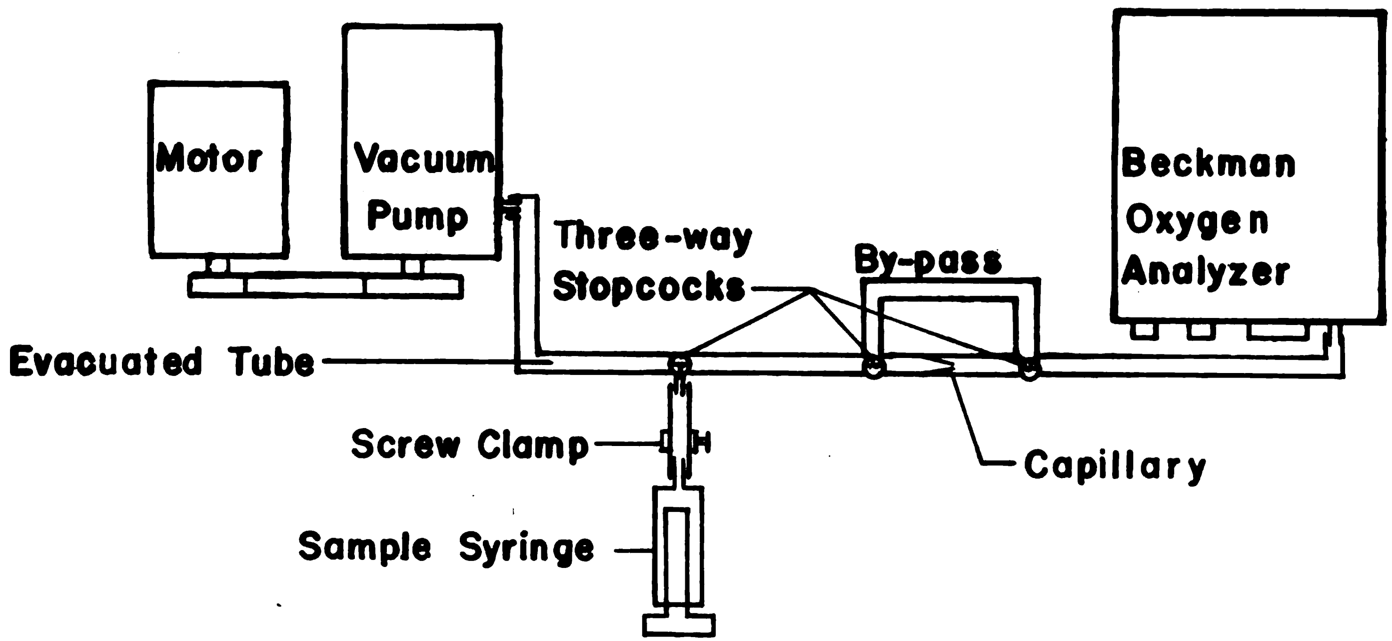

Figure 11. Beckman Gas Circuit

Figure 12. Oxygen analysis equipment

PROCEDURE

The two types of oxygen collection methods are the steady state and integral. The steady state method has several advantages over the integral method. It is used when the oxygen intake rate is constant, therefore, any aspirating of air by the sample bladder when it is at low pressure will have no affect on the test. Also any stagnate air that might be in the valve, rubber tube or Kofranyi meter will probably be of the same oxygen content as that which is being expired during the test. The integral method is based on the assumption that the repayment of the oxygen debt by the body is entirely efficient. The integral method has the advantage that it can be used on tests of short duration and tests where a steady state level of oxygen consumption is not reached.

The tests used in this study were all of the integral type, however, the procedure for steady state tests is given also. The procedures given here are similar to those used by Insull (16) in tests at the Army Nutrition Laboratory.

The subjects were oriented to the equipment before any tests were administered. The tests were conducted at least two hours after the subject had eaten. Fifteen to twenty minutes were allowed before a test to permit the subject to reach the basal energy consumption level.

A standing basal was run before each working test. The basals were conducted as a six minute integral test with the subject standing in position to begin work; the same position he would be in during recovery. All the basals were made standing on the ground except those for the climbing tests, which were made while the subject was standing on the steps in the silo chute. Standing in the chute required more Calories per minute than standing on the ground, which points out the importance of taking a basal test in exactly the same position as is used in the recovery period.

The data sheet used for the tests is shown in Appendix I.

<u>Silage pitching tests</u>

There were four subjects used in the silage pitching tests. Three tests were conducted with subject 1, four tests with subject 2, five tests with subject 3, and thirteen tests with subject 4. The largest number of tests were carried out on subject 4 to collect enough data to analyze the affect of some of the variables on the amount of energy used in removing silage from a silo. The tests were executed in a fourteen foot diameter silo located on the Michigan State University farm. This limited the tests to one each day.

All subjects were familiar with the procedure used in removing silage from a silo. The corn silage was removed in layers of between three and four inches each. Each layer was started at the door and continued across the silo. There was approximately 120 forksful of silage in each layer.

The subjects were instructed to work at their normal speed;

the work rates varied from 5.2 forks per minute to 9.3 forks per minute. They were also told to try pitching full forksful during the test.

The silage was weighed for several tests and the weight per forkful computed. It was found that the weight per forkful could be estimated quite accurately. Thus the amount of silage removed was estimated for most tests, with spot weighing checks.

The height the silage had to be pitched varied from zero to twenty-four inches.

The fork used in the test was fifteen inches wide and had ten tines 16.5 inches long.

The recovery period after the tests was carried on until the subject's pulse rate returned to the pre-work level.

Climbing tests

Two subjects were used for the climbing tests. Subject 2 enacted four climbing up and down tests and two climbing up tests. Subject 4 carried out five climbing up and down tests, seven climbing down tests and sixteen climbing up tests. Subject 4 was the only subject who executed enough chute basals to obtain an average of this type of test.

The tests were conducted at speeds varing from 28 feet per minute to 60 feet per minute. The silo used for the climbing tests had steps of two sizes. The subject climbed each size step alternately, placing both feet on each step. The size of one step was 9.5 inches and the other was 18.5 inches high. The subjects climbed to a height of 28.5 feet during each test. The climbing up tests and the climbing down tests were carried out for a total test time of six minutes. The climbing up and down tests were administered for a total time of nine minutes.

Treadmill tests

Subject 2 executed 4 tests, subject 3 did 3 tests, and subject 4 ran 8 treadmill tests. The treadmill tests were made at 2.54 feet per minute (1.75 mph). The subject walked for two minutes; the total length of the oxygen collection period was six minutes.

Integral tests

1. The Kofranyi meter was strapped in place.

2. The connecting hose was fastened to the meter and to the plastic valve.

3. The mouthpiece was placed in the mouth and the plastic valve checked to insure proper operation.

4. The nose clamp was put in place and checked for air leaks.

5. The aliquot bladder was evacuated orally, clamped and put in place.

6. The subject stood at rest, breathing through the meter, ready to begin work, for five minutes (see figures 8 and 9).

7. The initial volume and temperature were read.

8. The clamp on the aliquot bladder was removed, the metering lever was turned, and the stopwatch was started.

9. The subject started work, worked a predetermined amount, stopped and the time when work stopped was recorded.

10. The subject stood at rest until he returned to normal standing energy consumption rate. This was determined by checking the pulse rate until it returned to pre-work rate. The meter was stopped and the aliquot bladder was clamped.

11. The final temperature and volume were read.

12. The aliquot bladder was sampled.

Steady state tests

1. The collection meter was placed on the subject and checked as in steps one through five above.

2. The subject began work and continued until he reached the steady state energy usage level.

3. The initial volume and temperature were read.

4. The clamp on the aliquot bladder was removed, the metering lever was turned, and the stopwatch was started.

5. The subject resumed working and worked a predetermined amount, then stopped.

6. The time was noted, the meter stopped and the aliquot bladder clamped.

7. The final temperature and volume were read.

8. The aliquot bladder was sampled.

Handling of gas samples

1. The aliquot bladder was removed from the Kofranyi meter,

checked to see that it was not excessively full, and kneaded well.

2. The bladder was connected to a three-way stopcock along with a glass syringe (see figure 10).

3. The connecting hoses were evacuated orally.

4. The syringe was flushed three times with expired air samples of from five to ten milliliters each.

5. A twenty-five to thirty milliliter sample was drawn into the syringe, and the connecting hose clamped with a screw clamp.

6. Two syringes were taken from each sample bladder, providing the sample was large enough.

<u>Oxygen analysis</u>

1. The power was turned on and the Beckman was allowed to warm up for thirty minutes.

2. The span setting of the analyzer was checked.

3. The system of connecting tubing was evacuated.

4. The system was purged with the gas sample to be analyzed.

5. The pilot light was turned on and the Helipot Duodial was turned until the light was centered on the vertical black line.

6. The reading on the Duodial was taken and the oxygen percentage of the sample computed.

7. A second sample was analyzed for each syringe.

<u>Processing of data</u>

1. Information needed

a. Volume of gas expired

1) Kofranyi correction factor

b. Temperature of expired gas

c. Barometric pressure

d. Oxygen percentage of expired gas

e. Outside air temperature, dry bulb

f. Outside air temperature, wet bulb

2. Method of processing

a. The recorded volume was corrected for the meter factor; this factor was taken from figure 6, with the Kofranyi flow rate taken as two times the average flow rate for the entire work time. This was to allow for inspiration time while breathing.

b. The expired air was assumed to be saturated with water vapor. The volume was corrected to dry air at standard temperature and pressure, using the nomograph in figure 13 to obtain the correction factor.

c. The oxygen percentage was corrected for background gases by reducing the indicated percentage by -0.19%.

d. The oxygen percentage was corrected for moisture content of the gas sample by the factor obtained using the formula on page 25. The correction factor for the outside air was subtracted from the one for the expired air sample.

e. The calories per liter of expired dry air were determined from Weir's nomograph (30). The nomograph is shown in figure 14.

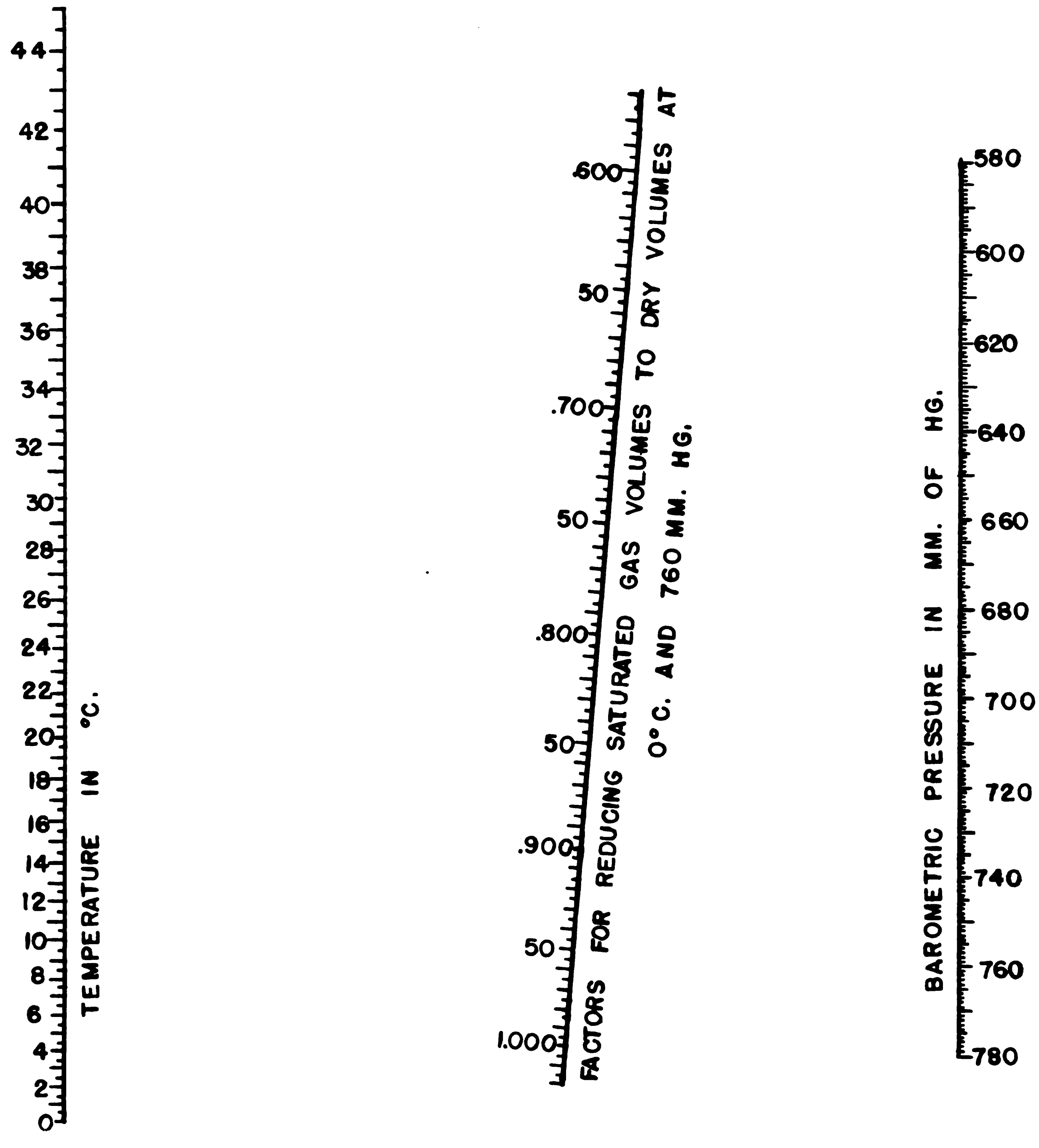

Figure 13. Nomograph For Determining Factors To Reduce Saturated Gas Volumes To Dry Volumes At 0°C. And 760 mm. Hg. From Reference 7.

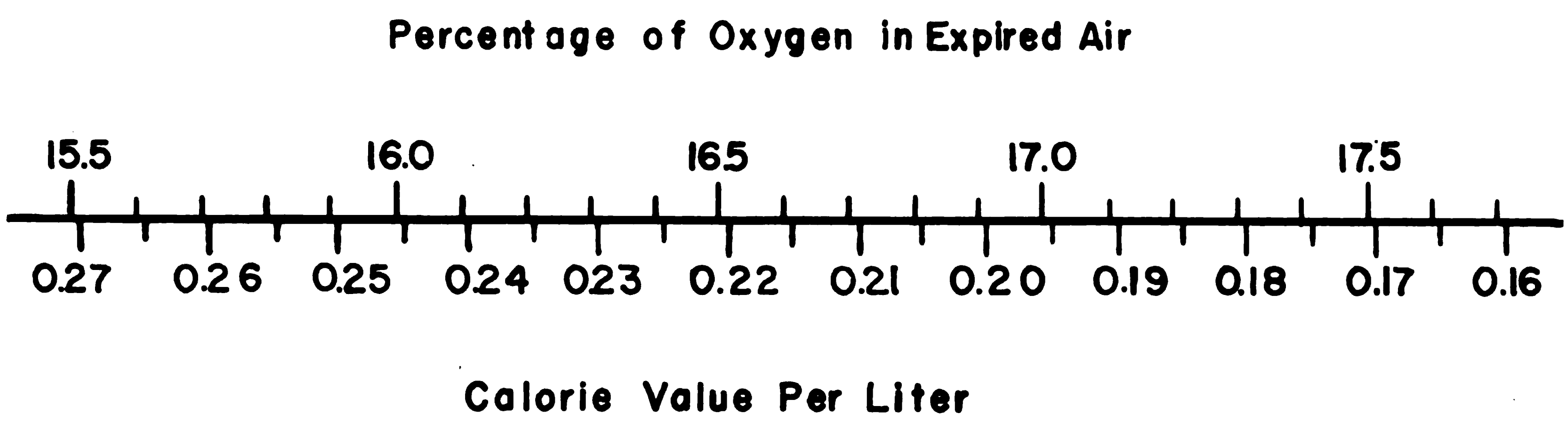

Figure 14. Nomograph for Determining Calorie Value Per Liter From Oxygen Content of Expired Air.

From Reference 30.

f. The calories per liter of expired dry air were multiplied by the corrected volume of expired gas to obtain total calories for the work done.

g. The calories required for the basal standing test were then multiplied by the necessary factor to give total basal calories for the same length of time as the working test.

h. The basal standing calories were subtracted from the total calories to give work calories for that test.

i. The subjects were compared by dividing the work calories for doing a task by their body's surface area. The surface area of the body was found by using the subject's height and weight and the nomograph shown in figure 15.

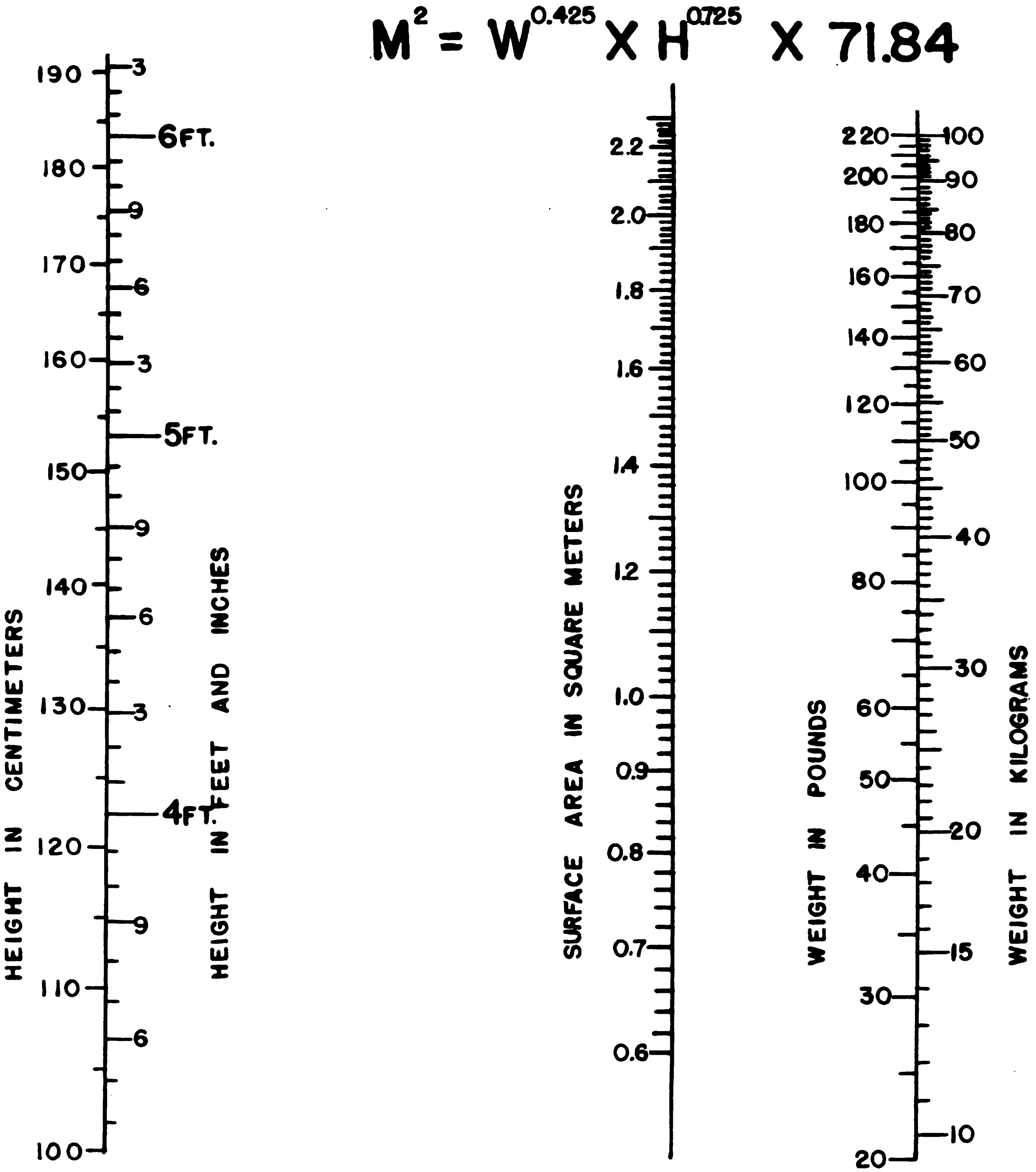

Figure 15. Nomograph For Finding Body Surface Area From Height And Weight. From Reference 7.

RESULTS

Subjects

Subject 1 is approximately 66 inches tall and weighs 155 pounds. From figure 15, his body surface area was found to be 1.8 square meters. He is experienced in doing farm chores.

Subject 2 is approximately 67 inches tall and weighs 160 pounds. His body surface area is 1.84 square meters. He has spent all his life on a farm.

Subject 3 is 75 inches tall and weighs 215 pounds. His body surface area is 2.29 square meters. He is not from a farm, but he has had limited farm experience.

Subject 4 is 67 inches tall and weighs 165 pounds. His body surface area is 1.88 square meters. He is experienced in farm chore operations.

Basal tests

The results of the basal tests are shown in Table 1. The results are given with the standard error of the means for both the test results and for the results corrected for the size of subject. Figure 16 shows in bar graph form, the comparison of the subject's basal tests.

Statistically, there is significant difference in the corrected basals between only subject 3 and the other subjects. The t-test was used to compare the subjects. The comparisons are:

$t_{1,2} = .56$ $\qquad\qquad$ $t_{1,4} = .059$

TABLE 1. RESULTS OF THE BASAL TESTS

STANDING ON THE GROUND

Subject	No. of Tests	Energy used in Cal/min.	Energy used in Cal/min-m^2	Standard error of the mean
1	3	1.47	0.815	0.0603
2	6	1.57	0.855	0.0384
3	5	2.38	1.038	0.0370
4	13	1.52	0.811	0.0306
	Average	1.80	0.880	

STANDING IN THE SILO CHUTE

Subject	No. of Tests	Energy used in Cal/min.	Energy used in Cal/min-m^2	Standard error of the mean
4	12	1.80	0.957	0.0185

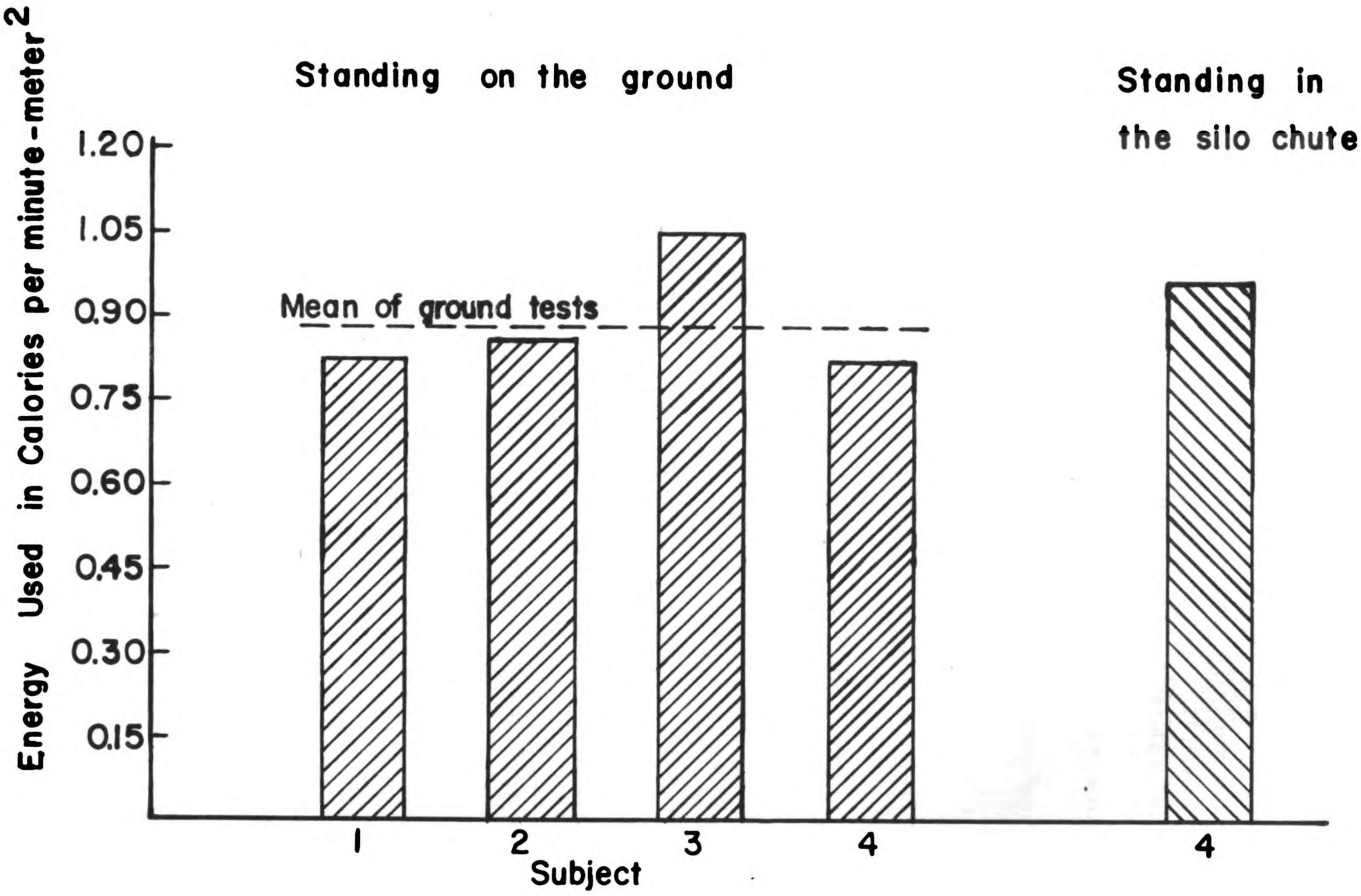

Figure 16. Results of Basal Tests

$t_{1,3} = 3.22$ $t_{2,3} = 3.43$

$t_{2,4} = .895$ $t_{3,4} = 4.73$

Anything above 2.26 is significant to the .05 level.

The average of the basal tests for all four subjects is 0.88 Calories per minute-square meter. The average without correcting for the size of subject was 1.8 Calories per minute. This is exactly the same as Morris (23) lists as the average energy consumption rate for standing.

A comparison of the standing on the ground and the standing in the silo chute basal tests of subject 4 gives a "t" of 4.07. This means there is a significant difference between the energy required for these two types of basals.

Pitching silage tests

The results of the tests on removing silage from a silo are shown in Table 2 and in figure 17. There are significant differences in the amount of energy consumed between all subjects except 1 and 4. The comparison of the subjects are:

$t_{1,2} = 2.94$ $t_{1,4} = .573$

$t_{1,3} = 4.38$ $t_{2,3} = 6.68$

$t_{2,4} = 3.58$ $t_{3,4} = 4.11$

Anything over 2.26 is significant to the .05 level. This shows that the energy required for getting down silage differed more between subjects than the energy required to stand at rest. This is more apparent when the deviation of each subject from the

TABLE 2. RESULTS OF THE SILAGE PITCHING TESTS

Subject	No. of Tests	Energy used in Cal/lb.	Energy used in $Cal/lb\text{-}m^2$	Standard error of the mean
1	3	0.066	0.0366	0.00139
2	4	0.058	0.0315	0.00103
3	5	0.1111	0.0485	0.00233
4	13	0.0705	0.0375	0.00132
	Average	0.0764	0.0386	

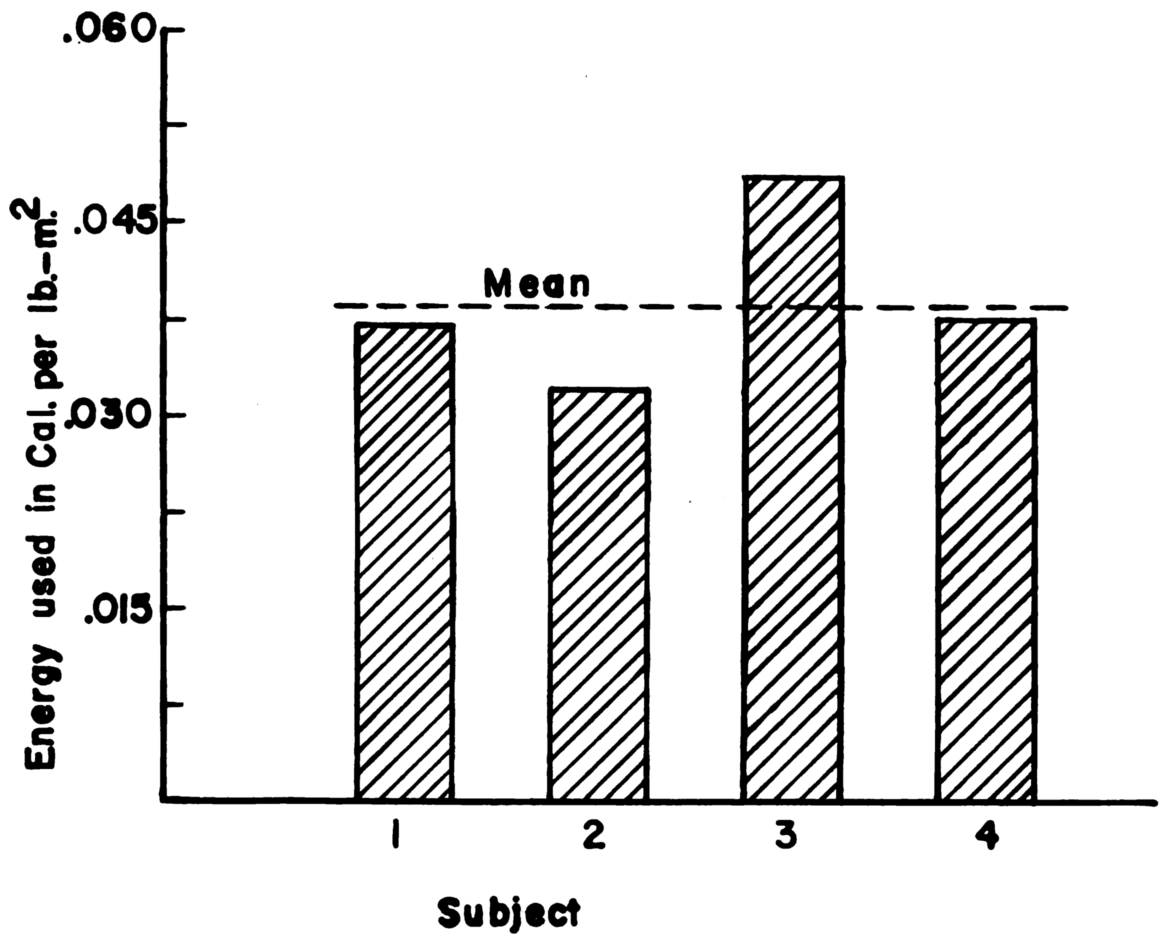

Figure 17. Results of the Silage Pitching Tests

mean is computed. The formula $Z = \frac{\bar{X} - X}{\sigma}$ is used.

Subject	Basal Z	Silage Z
1	.335	.27
2	.129	.957
3	.815	1.336
4	.357	.148

The affect of speed of work and silo position on the energy used by subject 4 in pitching silage is shown in figure 18. The speed of work is the average of the entire work period. The silo position is measured from the door to the centroid of the portion of silo area removed during each test.

Figure 19 shows the affect of door height on the energy required by subject 4 in hand pitching silage from a silo. The least squares line for this relationship has the formula, $Y = .0608 + .0695 X$. In this formula, X is the door height in inches and Y is energy used in Calories per pound.

The average amount of energy required to pitch silage from the silo was 0.0386 Calories per pound of silage removed per square meter of subject skin area. The average speed in this study was about 7 forks per minute. The average size of forkful was 19 pounds. Thus, the energy cost in terms of time would be 308 Calories per square meter-hour. The work intensities have

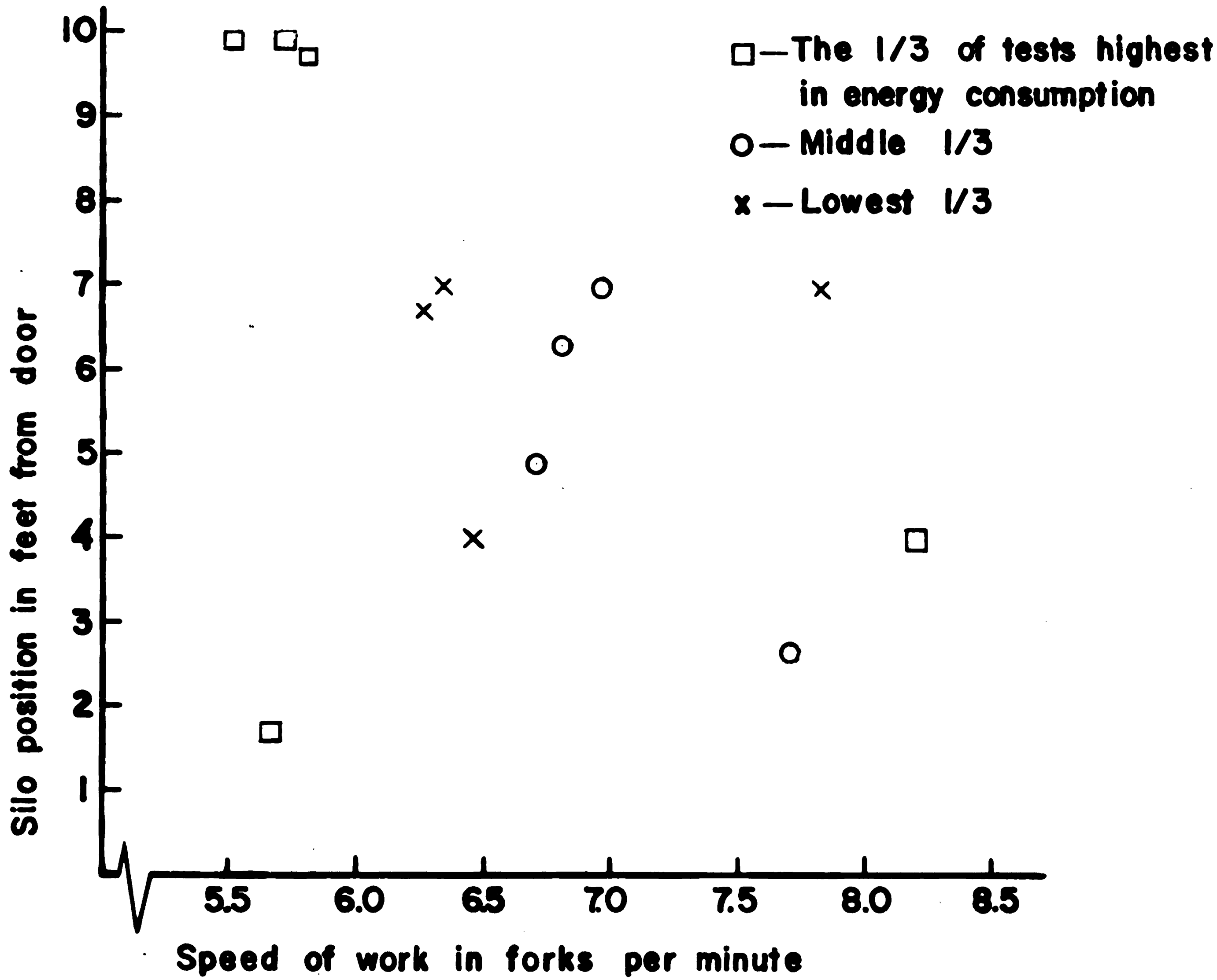

Figure 18. Effect of Silo Position and Speed of Work on the Energy Used by Subject 4.

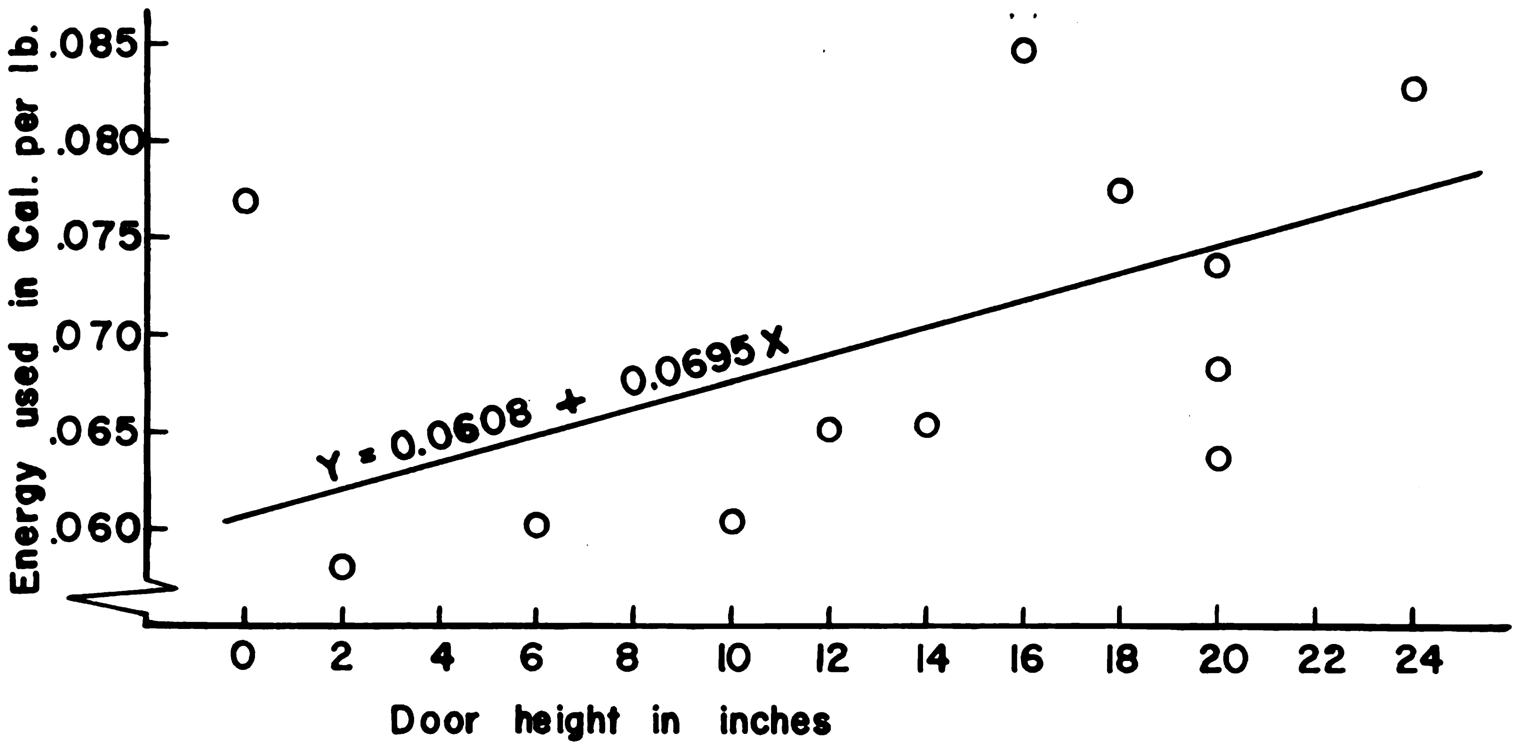

Figure 19. Effect of Door Height on the Energy Used by Subject 4 While Pitching Silage

been classified (22) as shown in figure 20. Three hundred and eight Calories per square meter-hour falls in the range listed as heavy work. The heavy work range is described as being tolerable for one hour.

Morris (23) lists the energy requirements of shoveling grain. Using a twenty pound load, with ten shovels per minute, he related that the energy cost of shoveling the grain six feet horizontally would be 7.2 Calories per minute.

The average amount of energy used to pitch silage from the silo in this study was 5.1 Calories per square meter-minute. For an average sized person, with a body surface area of two square meters, the energy consumption rate would be 10.2 Calories per minute. This compares quite closely with the data given by Morris, for pitching silage would require more effort in loading the fork than pitching grain. The silage also had to be pitched to an exact location which would tend to raise the energy usage rate.

Climbing silo tests

Table three is the results of the climbing tests. Comparing the subjects; $t = 1.30$ for the up and down tests and $t = 1.16$ for the climbing up tests. This is not a significant difference between subjects.

When the energy used by subject 4 during the climbing up the silo tests was added to the energy consumed during the climbing down the silo tests, the total was greater than the energy used in

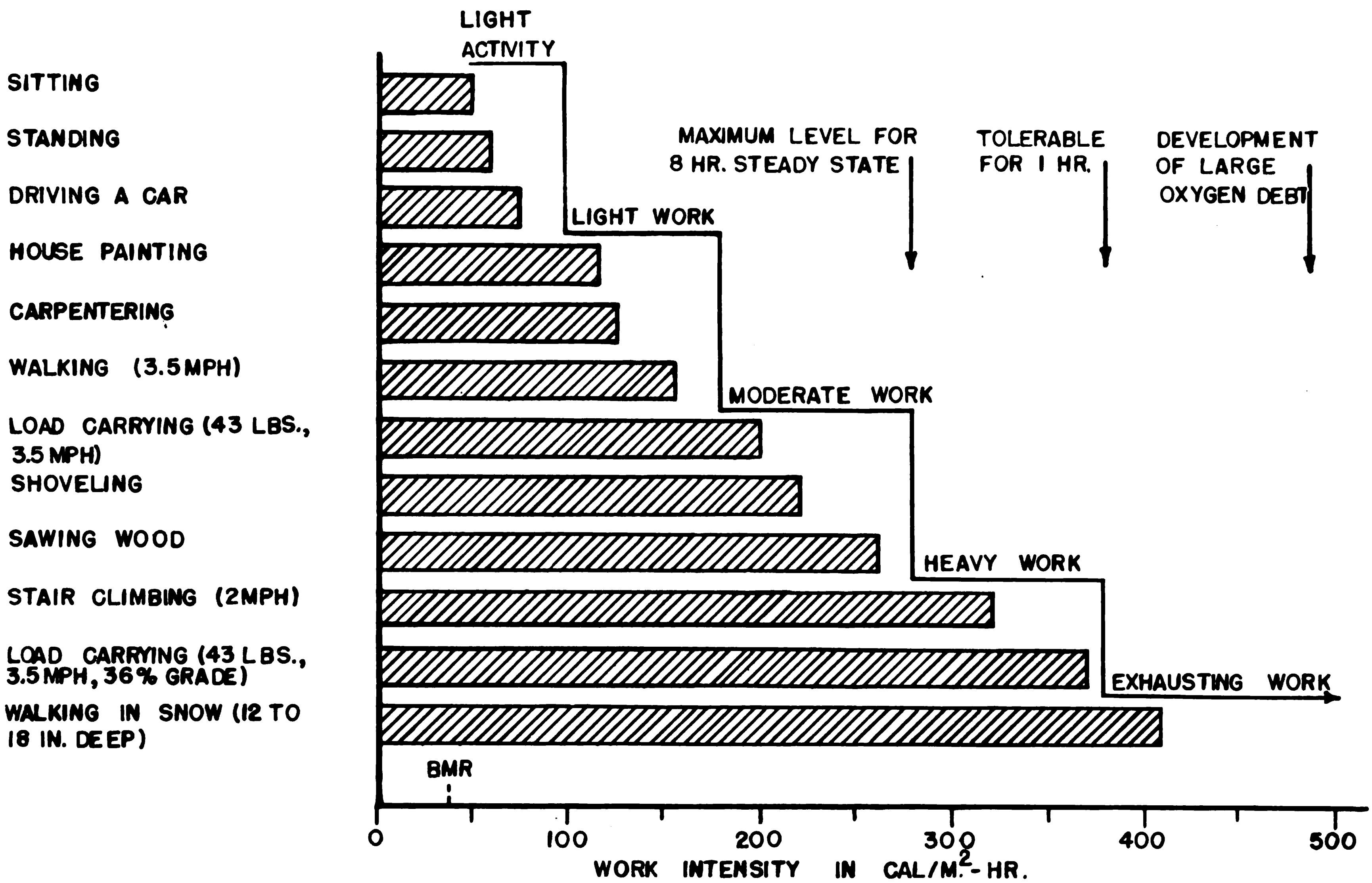

Figure 20. Comparative Energy Requirements for Selected Farm Activities. From Ref. 22.

TABLE 3. RESULTS OF THE CLIMBING TESTS

Climbing up tests

Subject	No. of tests	Energy used in $Cal/ft\text{-}m^2$	Standard error of the mean
2	2	0.218	0.0065
4	16	0.201	0.0082

Climbing down tests

Subject	No. of tests	Energy used in $Cal/ft\text{-}m^2$	Standard error of the mean
4	7	0.0758	0.0046

Climbing up and down tests

Subject	No. of tests	Energy used in $Cal/ft\text{-}m^2$	Standard error of the mean
2	4	0.248	0.0090
4	5	0.232	0.0085

the climbing up and down tests (see figure 21).

There was no correlation between the speed of climb and the total amount of energy required by subject 4 while climbing the silo. Climbing up the silo used energy at the rate of 450 Calories per square meter-hour.

Treadmill tests

Table 4 and figure 22 show the results of the treadmill tests. The subjects compared as follows:

$t_{2,3} = .48$ $\quad$ $t_{2,4} = 1.79$ $\quad$ $t_{3,4} = 2.81$

Anything above 2.26 is significant to the .05 level. Therefore, subjects 3 and 4 are significantly different in energy consumption. There was, however, less difference between subject 3 and the other subjects in this test than in any of the tests conducted.

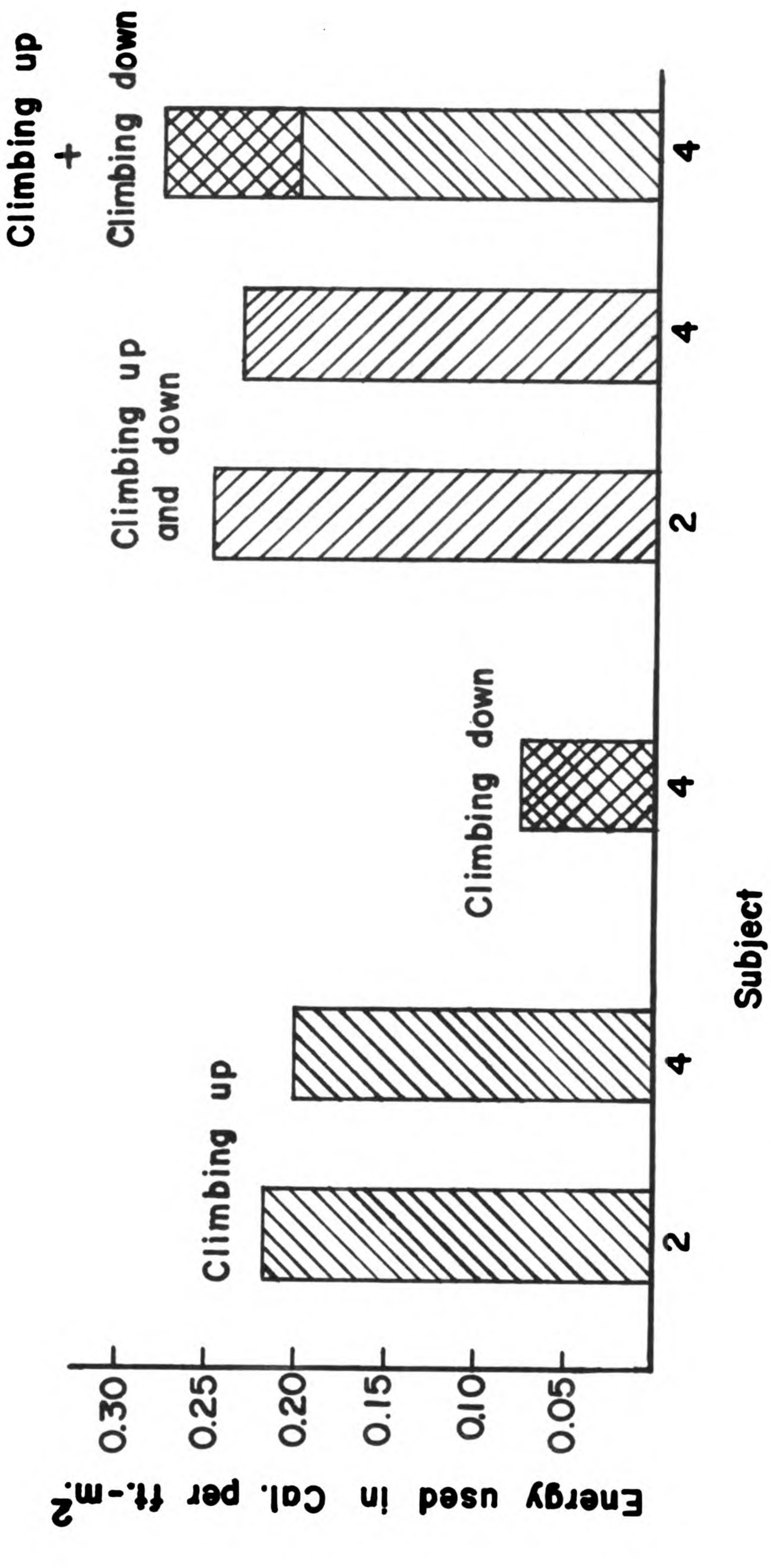

Figure 21. Results of Climbing Tests

TABLE 4. RESULTS OF THE TREADMILL TESTS

Subject	No. of Tests	Energy used in Cal/min.	Energy used in Cal/min-m^2	Standard error of the mean
2	4	1.89	1.03	0.0524
3	3	2.44	1.06	0.0347
4	8	1.78	0.913	0.0392
	Average	2.04	1.00	

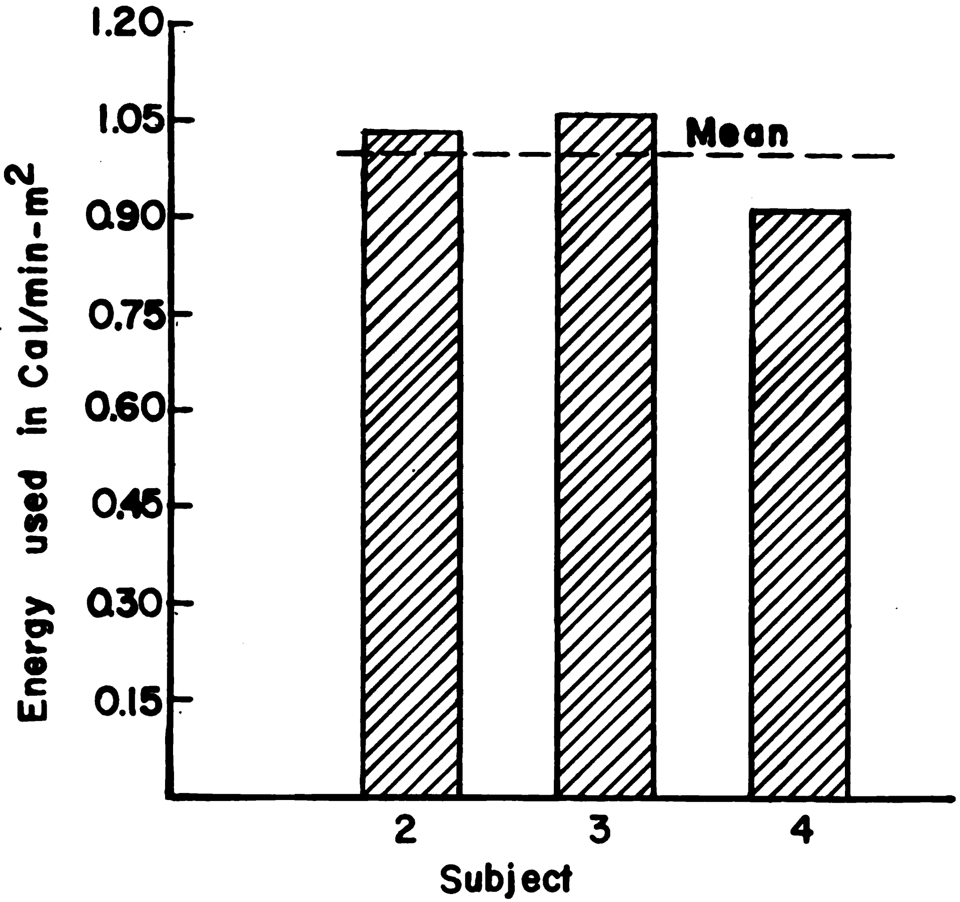

Figure 22. Results of the Treadmill Tests

DISCUSSION

Subjects

Subjects used in a study are important; there are variations in the energy usage levels between individuals that are not completely corrected for by use of the body surface area. Subject 3 used more energy than the other subjects on all tests. His usage rate for the treadmill tests was much nearer to the other subjects than for the basal or pitching tests.

The technique used by the subject is important in the amount of energy used. Subject 2 used more energy than subject 4 for the standing basal tests, however, subject 2 used less energy for getting silage out of the silo. Subject 2 used more energy to climb the silo and to walk on the treadmill. Subject 2 appeared to be working easier when he was pitching silage than the other subjects. Subject 3 had the worst technique in the silage pitching tests, however, with his long legs, he could walk on the treadmill at a easy pace.

Basal tests

Standing at rest was taken as the basal test in this study. The corrected basal tests for three of the subjects were not significantly different from each other, however, one subject was different. The basal energy requirements of the subjects did not vary with the time of day, and the temperature did not have a definite affect on the standing metabolism rate. The results indicated, however, that the basal rate would rise if the subject became chilled at low temperatures.

Silage tests

The results of the removing silage tests had greater variation between subject than the basal tests. This might be expected because of more variables. Figure 16 shows two of the factors affecting energy rate and their relationship to the energy required by subject 4. This relationship between speed, silo position and energy-used would be characteristic for any subject and not necessarily the same for any two subjects. Subject 4 was the only subject who executed enough tests in this study to enable these comparisons to be made. The associations would probably be the same general shape for all subject but would likely be of different magnitude.

The height to the bottom of the door, i.e: the height the silage had to be raised to be thrown out, had a slight affect, more energy being required at the highest levels. Figure 17 shows the least squares line for the relationship to have a slope of 0.0695.

One steady state test was run by subject 2. Despite a short warm up period, the results compared closely to the mean of the integral tests for subject 2.

Costs of pitching silage

Asmus (1) in a study at Ohio State has found the cost of a surface silo unloader to be $1.08 per ton of corn silage removed from a silo of 140 tons per year capacity. This is a cost of $.54

if 1,000 pounds of silage is removed.

It has been shown (23) that the maximum weekly energy consumption rate should be 18,000 Calories. Using a sixty hour work week, this is 300 Calories per hour. With a hourly wage rate of $1.50, the price per Calorie would be .5 cents.

Since it takes 0.0386 Cal/lb-m^2, an average sized person would use 38.6 cents worth of Calories in pitching 1,000 pounds of silage. The cost of climbing the silo is 5.7 cents for a height of twenty feet. The total cost for the energy used by a man at a price of .5 cents per Calorie is 44.3 cents. This is 10 cents less than the mechanical unloader cost.

The above method of placing a price on Calories was not entirely equitable. There was no allowance made for personal convenience of the silo unloader for the farmer. The rate was made for the maximum number of calories that a person is supposed to use, hence if he averages a smaller number than this, the price per Calorie would rise. The subjects in this study had an average power output of about 0.24 horsepower. A worker would not be expected to work this hard at all times.

The saving of cost is not the only consideration in comparing a mechanical unloader to a man; if an unloader is used, the man is free to do other gainful work on the farm. A man, in most instances can not compare to a machine as far as the cost of work output in horse-power is concerned. The advantage of the man over the machine is his ability to think and use judgement, and the use of machines makes it possible for him to better utilize these capabilities.

Climbing tests

The results showed that speed of climb had very little if any affect on the total energy required to climb to the top of the silo. The energy usage rate was, of course, higher at the faster climbing rates. The reason for the total of the climbing up tests and the climbing down test being greater than the climbing up and down tests is unknown. It may show that the integral tests should be used only where there is a constant energy expenditure rate.

Treadmill tests

The treadmill tests were run mainly to give a further comparison on the subjects used in this study, with each other and with any future studies. The results show that while subject 3 was much higher in energy consumption on the other tests, he was very near to the other subjects in the treadmill tests. This could be due to the speed of walking during the test. The other subjects were short, while he was tall, therefore, he was walking much slower with respect to normal while moving at the test speed.

CONCLUSIONS

1. The energy used by a man doing farmstead operations can be measured under field conditions.

2. The subjects should be chosen carefully to obtain a true average result.

3. At least four subjects should be used to obtain the average energy usage rate of a task. More subjects would be preferable.

4. One subject can be used to analyze the affect of variables on the energy used by a man doing a job.

5. The steady state oxygen collection procedure should be used whenever the tests are long enough to permit.

6. The average amount of energy required to pitch silage from an upright silo is 0.0386 Calories per pound of silage removed per square meter of body surface area of the remover.

SUMMARY

The energy used by an individual can be determined by measuring the amount of oxygen he used. In this study, a Kofranyi meter was used to measure the amount of air expired by a subject in doing a specific task. The meter also collected a sample of the expired air. This sample was analyzed in a Beckman oxygen analyzer to determine its oxygen content. From these data the energy used by the subject in doing that task was calculated.

The position of standing at rest was taken as the basal energy consumption level. The energy used in standing at rest was subtracted from the total energy required to do a task to give the work energy consumed by the person doing that job. The subjects used in this study had an average standing energy rate equal to the rate listed by Morris (23) as the standard.

The integral method of determining the oxygen used in doing a specific amount of work was used in this study because of the short time duration of the tests. The integral method collects oxygen from the start of work to the end of the recovery period.

Four subjects were used in 25 silage pitching tests. One subject executed more tests than the others to accumulate sufficient data to analyze the variables affecting the energy used in pitching silage. Two subjects were used in 34 climbing tests and

three subjects were used for 15 treadmill tests.

The tests show that throwing silage from a silo is heavy work, which is described as tolerable for one hour. Climbing the silo, though only one minute or less in duration was even higher in energy consumption rate than pitching silage.

The tests, except for those conducted on the treadmill, were carried out under field conditions; exactly as a farmer would encounter in doing his chores. The variation in the individual tests was no greater when conducted in the field than when carried out under laboratory conditions.

SUGGESTIONS FOR FUTURE STUDIES

1. A study might be conducted on the affect of running two tests of unequal energy usage rates in one integral test. This could have an affect on the results of all integral tests, for if there is an error, a slowing up of the work rate during the tests would influence the results.

2. The energy usage rates of other farm chores operations could be conducted.

3. The design of farm building layout and equipment arrangement could be examined by using minimum energy methods.

4. After sufficient data have been accumulated, a study in the field of production economics could be made to determine a price to be placed on each unit of energy.

5. A study could be made on the comparison of the human energy cost of doing farm chore operations with the machine cost of doing the same operations.

6. A remote pulse rate recorder could be used to supplement the oxygen consumption method of determining the effort required for a task.

REFERENCES

1. Asmus, R.W. (1957). Silo unloaders on Ohio farms. Agri. Ext. Bul. 360. Ohio State University, Columbus, Ohio. 8pp.

2. Battles, K.U. (1950). Factors of dairy barn design and equipment which influence labor requirements and milk quality. Thesis for degree of M.S., U. of Illinois, Champaign, Illinois.

3. Beckman, Inc., Arnold O. (No date). Model E2 oxygen analyzer operating instructions and technical information. Bulletin 203-A, Arnold O. Beckman, Inc., South Pasadena, California. 10pp.

4. Belding, H.S. and T.F. Hatch (1955). Index for evaluating heat stress in terms of resulting physiological strains. Heating, Piping & Air Conditioning 27:129-136.

5. Bowen, W.P. (1904). Changes in heart-rate, blood-pressure and duration of systole resulting from bicycling. Jour. of Physiology 11:59-75.

6. Clayton, J.T. (1951). Study of energy requirements for selected farm chore operations. Thesis for degree of M.S., U. of Illinois, Champaign, Illinois.

7. Consolazio, C.F., R.E. Johnson, and M.A. Marek (1951). Metabolic Methods. C.V. Mosby Co., St. Louis. 471pp.

8. Crowden, G.P. (1932). Muscular Work, Fatigue and Recovery. Sir Isaac Pitman and Sons, London. 74pp.

9. Dill, D.B. (1958). Regulation of heart rate. In Proceedings of First Wisconsin Conference on Work and the Heart. Hoeber-Harper, in press 1958.

10. Dressel, G., K. Karrasch, and H. Spitzer (1954). Investigation of the work physiology of shoveling, carrying concrete blocks and pushing a wheelbarrow. Translated from Zentralblatt fur Arbeitswissenschaft and Soziale Betriebspraxis 8(3): 33-48.

11. Dupuis, Heinrich (1957). Farm tractor operation and human stress. ASAE paper no. 57-511. Translated from Institute fur Lanwirtschaftliche Arbeitswissenschaft und Landtechnik of the Max Planck Society for the Advancement of Science, Bad Kreutznach, and the Max Planck Institute fur Arbeitsphysiologie, Dortmond, German Federal Republic. 36pp.

12. Ford, A.B. and H.K. Hellerstein (1958). Energy expenditure by cardiac and non-cardiac factory workers. In Proceedings of First Wisconsin Conference on Work and the Heart. Hoeber-Harper, in press 1958.

13. Fulton, J.F. (1949). Howell's Physiology. 16th Ed. W.B. Saunders Co., Philadelphia and London. 1258pp.

14. Gould, A.G. and J.A. Dye (1932). Exercise and its Physiology. A.S. Barnes and Co., Inc., New York. 434pp.

15. Henderson, Y. and H.W. Haggard (1925). The circulation and its measurement. American Journal of Physiology 73:195-245.

16. Insull, William Jr. (1954). Indirect calorimetry by new techniques: a description and evaluation. Army Medical Nutrition Laboratory Report 146. U.S. Army Fitzsimons Army Hospital, Denver 8, Colorado. 32pp.

17. Karpovich, P.V. (1953) Physiology of Muscular Activity. 4th Ed. W.B. Saunders Co., Philadelphia and London. 340pp.

18. Lythgoe, R.J. and J.R. Pereira (1925). The pulse rate and oxygen intake during the early stages of recovery from severe exercise. Proc. Roy. Soc., London, S.B. 98:468.

19. Montoye, H.J., W.D. van Huss, E.P. Reineke and J. Cockrell (1958). An investigation of the Muller-Franz calorimeter. Internationale Zeitschrift fur Angewandte Physiologie Einschliesslich Arbeitsphsiologie Bd. 17, S 28-33.

20. Morehouse, L.E. and A.T. Miller (1948). Physiology of Exercise. C.V. Mosby Co., St. Louis. 353pp.

21. Morris, W.H.M. and L.L. Boyd (1955). Time and effort to milk cows. Ag. Engr. Journal 36:532-535.

22. Morris, W.H.M. (1956). The Purdue Farm Cardiac Project L.S.H. Rev. 1, Purdue U., Lafayette, Indiana. 23pp.

23. Morris, W.H.M. (1957). Energy expenditure and farm work efficiency. ASAE paper no. 57-620. Journal paper no. 1208, Purdue Agr. Exp. Stat. 22pp.

24. Morris, W.H.M., J.B. Liljedahl, and J.E. Wiebers (1957). Heat stresses in tractor operation. ASAE paper no. 57-512. Journal paper number 1209, Purdue Agr. Exp. Stat. 16pp.

25. Passport, R. and J.U.G.A. Durin (1955). Human energy expenditure. Physiological Reviews 35:801-840.

26. Riedman, S.R. (1950). The Physiology of Work and Play. The Dryden Press, New York. 584pp.

27. Roller, W.L. and J. Amerine (1957). Human energy requirements for various farm tasks. From the 1957-58 Summary of Reports, Regional Project NC-23.

28. Ross, I.J., G.W. Isaacs, and W.H.M. Morris (1957). Analysis of a farm materials handling system. ASAE paper no. 57-596. From a M.S. thesis by I.J. Ross., Purdue U. 13pp.

29. Suggs C.W. and W.E. Splinter (1956). Time and energy analysis of agricultural tasks. Prepared from work done at North Carolina by the authors. 12pp.

30. Weir, J.B. de (1949). New methods for calculating metabolic rate with special reference to protein metabolism. J. of Physiology 109:1-9.

31. Wiebers J. and G. Beals (1957). Physiological costs of driving farm tractors. ASAE paper no. 57-513. 12pp.

APPENDIX I

ENERGY DATA FORM

PROJECT ______________________________ DATE ______________

NAME _________________________________ OUTSIDE TEMP. _____

RACE ________ AGE ________ HEIGHT ________ WEIGHT ________

TYPE OF TEST ____

- -

Meter No. _______________ Constant __________ Fraction __________

Final Vol. _______________ Final Temp. ______ Time _____________

Initial Vol. ______________ Initial Temp. ______ From ____ To ______

Diff. Vol. _______________ Av. Temp. ________ Warm up ___ To ____

Corr. Vol. _______________ Barometer ________ Work _____ To _____

STPD Vol. _______________ STPD Factor ______ Collection ___ To ___

Initial Pulse _____________ Final Pulse ________________________

SYRINGE

No. ______

Run 1 ____ % O_2

No. _______

Run 1 ____ % O_2

Total Cal. ____________________ Ave. % O_2 ______________

Basal Cal. ____________________ Calories per liter _______

Work Cal. ____________________

Work Cal./Min. ______________