THE DETERMINATION OF THE PROPER ILLUMINATION FOR THE APPLE PACKING PLANT

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Marvin Edward Heft, Jr.

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By

Marvin Edward Heft, Jr.

A THESIS

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

MASTER OF SCIENCE

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ABSTRACT

Lighting of the apple grading operation requires a light source of the proper quality and quantity to enable the worker to detect defective apples with a minimum of time and effort and with maximum accuracy. The proper quality light source accentuates the maximum contrast between the normal apple surface and the defect. The proper quantity of light will provide a minimum of 25 footlamberts of product brightness.

The proper quality light source can be determined by theory or by observation. The theoretical method involves the determination of the best coefficient of correlation of a two-variable correlation between the visibility function curve of the various light sources and the contrast between the visibility function of the normal and defective apple surfaces. The observational method is simply observing the apple and its defects under the various light sources.

The proper quantity of illumination can be determined only when the surface brightness of the apple surface is known. Surface brightness is obtained by an equation using the reflectance of the apple as obtained by the spectrophotometer, the luminosity function, and the luminant energy output, or by a light meter measuring the incident light and the product brightness of the apple surface.

The average surface brightness of the red apple was 23.4 percent under the deluxe cool white fluorescent lamp, the recommended fluorescent lamp, and 24 percent under the 150-watt incandescent filament lamp. This means that to obtain 25 footlamberts of product brightness 178 footcandles of lighting is required when a medium duty service factor of 60 percent is used.

The required lighting of 178 footcandles on the surface of the apple is to be divided between general and supplemental lighting. General lighting should be at least 10 percent of the total, or 18 footcandles, to assure eye comfort of the worker. Supplemental lighting should provide the remaining 160 footcandles of shadowfree glarefree light on the working surface of the apple grader. Fluorescent luminaires should be mounted in a continuous row three feet above the center line of the grader. The incandescent filament luminaires with 150-watt reflector type lamps should be mounted three feet apart and four feet above the center line of the grader.

The deluxe cool white fluorescent lamp was the unanimous choice of the west Michigan apple packing plant owners in whose plants test installations of the recommended luminaires were made. The manager of the plant in which the 150-watt incandescent filament reflector type lamp was used was well satisfied.

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INTRODUCTION

Since the beginning of time man has worked and played in the light of the sun. Since the beginning of time man has attempted to provide light so that he could extend his working and playing day and move his activities indoors and not be affected by darkness of night and inclement weather. Lighting has developed from a fire in the cave to today's wide assortment of lamps. Technology for the application of the developing light sources has kept pace with the lamp development. The application of this technology to specific applications has been neglected in many areas. It is the aim of this investigation to apply technology to the problem of apple sorting.

Two of the problems that the Michigan apple grower faces in the marketing of his fruit are increasing packaging costs and the demand for a higher quality pack. Lighting has an effect on both.

Consumers are demanding a better quality pack and will not purchase produce that is inferior in quality. The demand for a higher quality pack is influenced by the convenient-sized prepackaged products offered in the self-service supermarkets (22).* Modern grading and handling equipment has done much to reduce bruising and other damage to the apple from harvest until it reaches the vendor's produce counter, resulting in a better quality pack.

Research in materials handling has eliminated much labor from the apple marketing program. Equipment such as fork lift trucks,

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*Refers to appended references.

pallet boxes, and mechanical box dumpers, allows one man to do the work of many, thereby lowering the packaging and handling costs.

Researchers have done much to aid the apple grower in reducing costs and improving the quality of the pack, but in all of this progress one factor has been forgotten, lighting. Can the worker at the apple grader see the defects? The human eye has a wide range of adaptation, but it does have limits. The demands on the eye are greater with the new equipment and higher quality requirements because of increased grader speeds and capacities and the more critical seeing needed to detect the defective fruit.

Researchers in pursuit of the answers to the apple grower's problems of increasing costs and the demand for higher quality have overlooked two facts; (a) eye strain caused by poor illumination causes fatigue and the lowering of worker efficiency; (b) as the time available for the detection of the defect decreases the amount of light necessary to detect the defect increases in order to maintain the same degree of accuracy of sorting.

Michigan and National Apple Production

Apple production is an important agricultural industry in Michigan and the United States. In the period 1947-56 the average annual value of the Michigan apple crop was approximately 13 million dollars. Since then the crop has been worth approximately 20 million dollars annually. The average annual production in Michigan for the period 1947-56 was more than 8 million bushels. The 1957 Michigan production was 10 million bushels and is estimated at 12 million for 1958. Michigan consistently ranks among the top five states in apple production. The 1958 estimate places Michigan in third place (23, 24).

Nationally, the annual apple production averaged more than 100 million bushels for the period 1947-56; the 1957 production was 118 million bushels and the 1958 production is estimated at 125 million bushels. The average annual value of the national apple crop for the period 1947-56 was 210 million dollars (23, 24). Approximately 80 percent of the apple crop is used for fresh fruit, which makes grading an important operation.

The Jonathan is Michigan's leading variety of apple, with an average annual production for the period 1946-54 of 1.5 million bushels; the McIntoch is second with 1.15 million bushels; the Spy, with 1 million bushels is third, and Red Delicious is fourth, with 760 thousand bushels. The Golden Delicious, the leading yellow variety, has an average annual production of 110 thousand bushels (23).

Scope of the Investigation

The aim of this investigation is to determine the proper commercially available luminaire, or luminaires, that will allow the worker on the apple grader to detect the defective apples with the greatest practical speed and accuracy and minimum of fatigue.

In order to accomplish this, three factors must be considered: (a) the proper level of illumination that will permit a maximum speed of detection of defects, (b) the illumination of the apple surface so that the maximum contrast will occur between the normal apple surface and the defect to be removed, and (c) the bringing of the entire apple surface into the field of vision of the worker. The third factor (c) will not be considered in this study because the majority of the modern apple packing plants rotate the fruit so that the entire surface of the apple is exposed to the field of vision of the worker.

The Apple Grading Operation

In general, all apple packing plants use the same basic operations and equipment, but here the similarity ends. Because of the great variety in building design, equipment design, and plant requirements, every grader installation is entirely different. A simple layout of the basic operating sections is shown in Figure 1.

The first operation in grading is dumping. Here the apples are dumped onto the grader either by hand or by a mechanical dumper. The worker at this point is required to remove the rotten apples before he feeds the apples into the cleaning operation. This operation is one requiring supplemental illumination.

From the dumping operation the apples move to the cleaning operation. In Michigan apple packing plants, the cleaning is done by rotating brushes or rags. The rotating brushes, or rags, make the apples shine by polishing the cuticle, the natural wax layer on the apple. Since cleaning is a mechanical operation, supplemental illumination is not required as the general packing plant illumination will be adequate for this operation.

After the cleaning operation comes the pickout operation. Usually a series of rollers, perpendicular to the direction of the apple flow, rotate the apples so that the worker, or workers, stationed there can view the entire apple surface and remove defective apples. Because the purpose of the pickout operation is the removal of defective apples, the illumination of this section is of utmost importance.

Next in line is the sizing operation. Here the apples are sorted into predetermined sizes. This is a mechanical operation with the sizing done by belts or chains or by weight. Supplemental illumination is not required in this area.

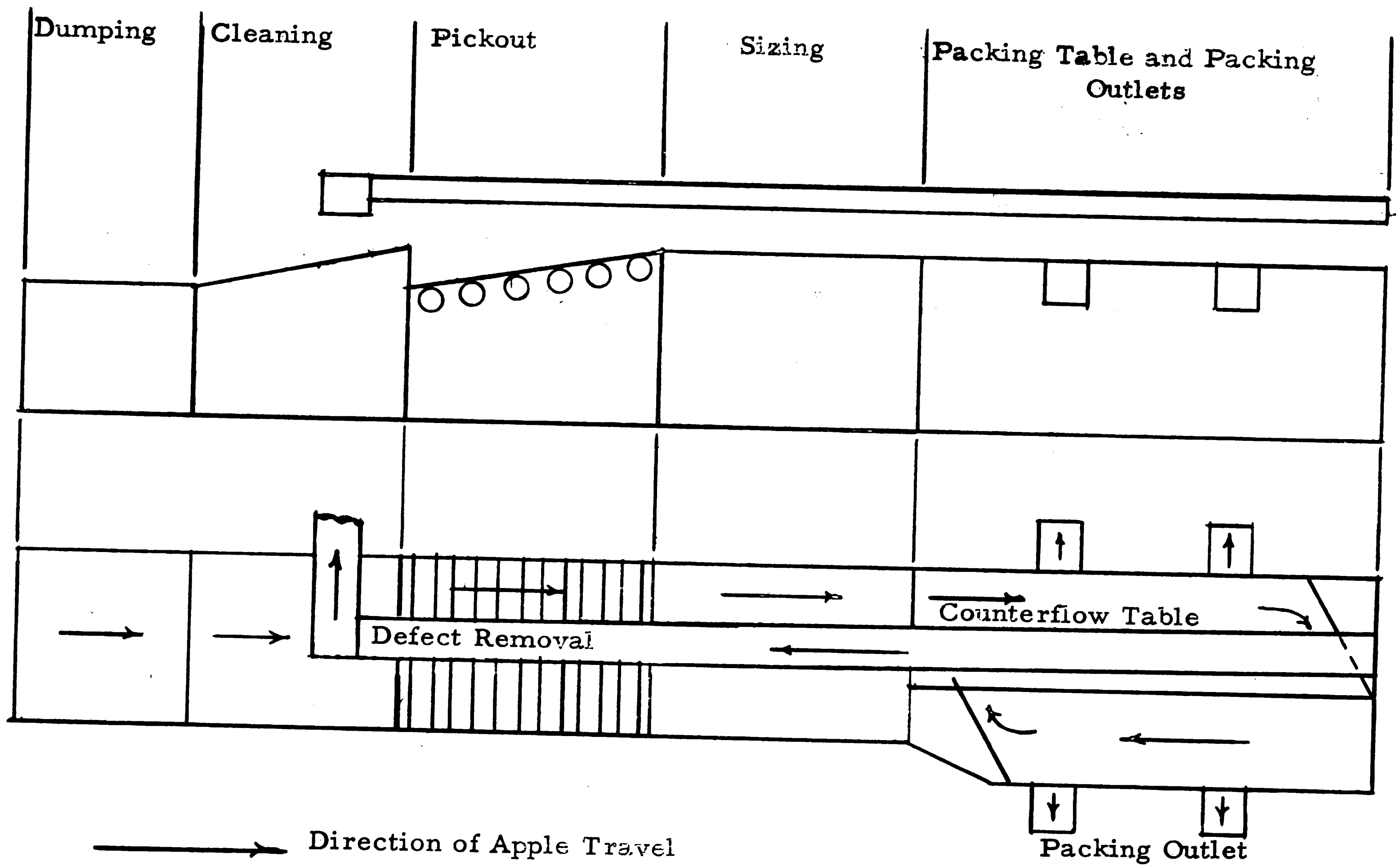

Figure 1. Typical Apple Grader Layout

The final operation in apple grading is performed at the packing table and packing outlets. The packing table may be either of two types. The simplest type is a sloping table down which the apples roll to the packer. This type is little used because of lack of capacity. The second type is a table of length needed for the production of the plant. It consists of counterflow belts that move the apples around the table until removed by the packers. Packers remove the apples through one of several methods.

The oldest and simplest pack is the bulk pack, where the apples are packed in a crate or apple box. Another method is bagging the apples into consumer-sized plastic bags. There are several ways of transferring the apples from the table to the bag. With the sloping table the apples are usually allowed to roll into the bag. With the counterflow table the apples are moved to the bag either by hand or by diverting rods that are placed in the stream of apples. In some cases filling the bags is an automatic operation, with the operator placing the empty bag onto the bagger and removing the full one. There is also the cell-pack method. The apples are removed from the packing table by hand and placed in individual cells in the shipping cartons.

In addition to the packaging of the apples the workers in this area make the final check on quality, as it is the duty of the workers to remove any defective apples that have been missed in the pickout area. This area must have supplemental lighting. Therefore it is one of the areas studied in this investigation.

Many Michigan apple packing plants have graders equipped with a belt for the removal of the defective apples. This belt is located over the center of the grader and a few inches above the working surface, a location that allows the workers to place the defective apples onto it with a minimum of time and effort. This location presents a lighting problem as the belt cuts off some of the overhead light causing shadows and low levels of illumination on the working surface, both of which reduces the efficiency of the packing operation.

Varieties Studied

The major emphasis of this study was the lighting of the red varieties of apples since they are the main varieties grown in Michigan. The yellow varieties were given some consideration, but the green varieties were not considered as they are used mainly for processing, and the grading operation is not as critical as it is for the fresh fruit market.

The major Michigan varieties, Jonathan, Spy, McIntosh, Common Delicious, and Double Red Delicious were used in this investigation. The Golden Delicious was the yellow variety studied. All samples used were selected by Dr. D. H. Dewey of the Horticulture Department, of Michigan State University, as being representative of the variety.

Defects Studied

Defects studied fall into two general categories; surface defects and off-colored fruit. Internal defects such as water core and internal breakdown cannot be detected by surface illumination and therefore are not included in this study.

There were several surface defects studied: (a) insect damage, which can be anything from a small surface scar to an open worm hole; (b) scab, a fungus growth on the surface; (c) breakdown (commonly called rot); (d) limb bruise, a darkening of the surface caused by rubbing by a tree limb; (e) bruise, a mechanical indentation of the surface that occurs at or after harvest and causes no change in surface color except as breakdown sets in. There are other defects but they are similar to the studied defects and the results obtained will apply to all defects. In general the defects are darker than the apple surface. One exception is apple scab.

Off-color apples are those apples that have not developed sufficient characteristic color to make the required grade requirements.

State and federal grade laws set the tolerances of the percentage of defective apples in a given grade. These laws also set the maximum size of defects and the minimum amount of characteristic colored area for the grade. Michigan grade requirements are shown in Table I (25).

The Problem

The problem that this investigation confronted was the determination of the light source or sources that would provide the greatest difference in visibility between the normal apple surface and the defect. The proper light sources will make it possible to obtain the maximum possible grade with a minimum of labor.

TABLE I

MICHIGAN APPLE GRADE REQUIREMENTS (25)

Limits of Defects in U. S. Apple Grades

Defect	Grade		
	U.S. Extra Fancy	U.S. Fancy U.S. No. 1	U.S. Utility
Decay	None	None	None
Jonathan spot	None	None	None
Scald	None	None	None
Scab	None	1/4"	3/4"
Broken skin, bruises	None, except slight ones caused by normal handling		
Limb bruises max. dia	1/8"	1/2"	1/10 of surface
Rust max. dia.	1/8"	1/4"	3/4"
Healed insect stings max. dia.	1/8"	3/16"	1/4"
Open worm holes	None	None	None

Color Requirements, percent normal surface, U.S. Apple Grades

Variety	Grade		
	Extra Fancy	Fancy	U.S. No. 1
Delicious, Golden	75%	75%	75%
Delicious, Red	50	25	15
Jonathan	66	33	25
McIntosh	66	33	25
Spy	50	25	15

OBJECTIVE

In the preceding section it has been established that apple production is of importance to the economy of the state of Michigan and the nation, and that there is a need for the improvement of the lighting of the apple grading areas of the packing plant. The purpose of this study is to determine the proper illumination for use in the apple grading area of the packing plant, therefore the following objectives have been established:

1. To determine the proper available light source, or sources, that will permit the removal of the defective apples with the maximum speed and accuracy and with a minimum of effort.
2. To determine the proper level of illumination (footcandles) using commercially available luminaires that will permit the removal of the defective apple with maximum speed and accuracy and with a minimum of efforts.

REVIEW OF LITERATURE

Illumination for Fruit Grading and Sorting

Ditchman (1958) said the main purpose in grading lighting is to light the defect to be detected in such a way as to make it stand out (maximum contrast) and at the same time light the things in the general field of vision so as to avoid harsh adjustment for the workers' eyes. The general illumination should be at least 10 percent of the total illumination if the workers' eyes are to be allowed to rest when he glances upward. If the background is dark the eyes tire quickly because they do not adjust easily to such marked contrasts.

Peterson (1951) reported on limited work on cherries:

> There is no artifical light found that does everything in culling work. Some lights enhance the color of the product, others show up certain defects better, and it is found also that the color of belts influence the color perceived, and they are of primary importance.

He also reported that the efficiency of the workers was influenced by the type of light, the background color, and the rotation of the fruit.

Additional work was done on cherries, as well as limited work on tomatoes, by Parker (1954), who obtained spectral reflectance curves of the main Michigan cherry varieties and their defects. He conducted tests on the effects of rotation of the fruit on the sorting efficiency.

Parker, further reported that for maximum perceptibility of color differences, the illuminant should radiate throughout the entire spectrum and be saturated in the area of the maximum difference between the reflectance curves of the fruit and those of the defects. The color of the background should be the average color of the products being separated. He did considerable investigation in the area of special filters, mounted over standard fluorescent lamps for use in cherry sorting.

Carrying this work further was Alsop and others (1958) working with the cherry processors to determine an illumination system using commercially available luminaires that would give the maximum efficiency of defect removal. Through a process of installing the various colors of "white" fluorescent lamps in luminaires, and varying the level of illumination and making personal observations, the team of observers came to the conclusion that the proper fluorescent color to use was the deluxe cool white for the red varieties. A level of illumination of 150-200 footcandles was recommended by this team. Tungsten filament lighting was satisfactory with the same level of illumination as recommended for fluorescent lighting. For the sorting of the dark cherries Alsop says, "For dark sweet cherries, the white, frosted incandescent lamps were the only ones giving satisfactory light. The difference in ease of sorting with these lamps and any fluorescent was astonishing."

Numerous publications by various state colleges and the USDA on the subject of packing plant layout and equipment were reviewed and the only one that mentioned lighting was the Michigan State University Special Bulletin 417, Equipment and Layout for Fruit Packing Houses by H. P. Gaston and J. H. Levin, which recommends 100 footcandles at all critical areas and 5-10 footcandles of general illumination. Either incandescent or fluorescent lamps may be used. If fluorescent lamps are used the lamp color should be either white or cool white. According to Levin (1958), their recommendations were taken from a previous USDA bulletin and supplemented by common practice.

Illumination for Grading Other Agricultural Products

Probably most of the work on illumination for grading agricultural products has been done on cotton. Nickerson (1946) says, "Good lighting is so important for cotton classification that the cotton industry goes to

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great lengths to provide it in classification rooms." It is further reported that the amount of light is not the only factor in a good cotton classification room, but good quality also is needed, and may be even more important than quantity. For cotton classification work it has been found that the best artificial light is one that matches natural daylight.

Nickerson further reported that fluorescent daylight lamps are widely used for general illumination, but that special care must be given when they are used for color grading. Fluorescent illumination provides a large source of low brightness light with little heat and good diffusion, making it an ideal light source providing its color characteristics would make it a satisfactory substitute for daylight.

While Nickerson has done most of her work on cotton, she reported (1956) that:

> . . . This relates to the importance of the spectral energy distribution of lighting to be used in color work. For cotton we have found that the combination of fluorescent and incandescent lighting described is quite satisfactory for classing the colors of cottons, most cottons being near-white. It does not follow that it will be equally successful for all agricultural products, nor that it will serve all purposes. It may be entirely satisfactory for inspecting or sorting purposes, but unsatisfactory for initial grading of a product.

Gould (1952) reported that color is not how you see it, but how you light it.

Illumination in Other Industries

The Illuminating Engineering Society in its recommendations for canneries (1950) goes into detail on the illumination of the inspection and work areas of the cannery, and discusses the reasons for its recommendations. They report that high contrast between the defect and the immediate surround is necessary for accurate inspection.

If the contrast is poor, there are two ways to remedy the situation. One is to paint the field of vision to a reflectance equal to the product being inspected, and the other is to increase the brightness of the product by increasing the illumination. The recommendation quotes Crouch (1945) who says 90 percent of the maximum ability to see contrast is obtained when the brightness of the product and the surround is at 20 footlamberts.

The recommendation goes on to say that there is a need for high visual acuity in inspection tasks and an increase can be obtained by control of brightness. Crouch says that 80 percent of the maximum visual acuity occurs at 25 footlamberts of product brightness.

Speed of vision is also affected by the brightness level and, according to Crouch, the speed of vision increases with an increase of product brightness. The size of the defect and the reflectance of the defect were varied in tests and in all cases as the brightness increased the speed of vision increased.

In actual illumination of the cannery, the recommendation calls for glarefree general illumination with the use of high intensity supplementary illumination at all critical seeing locations. The general illumination should be at least 10 percent of the level of the supplementary illumination. Luminaires should be located so that they provide shadow-free illumination at the working areas.

Taylor (1942) reported that when radiant energy in the visible spectrum strikes an object, part of the energy is reflected at the surface with little or no change in its spectral character. The rest enters the product to a varying depth and is transmitted, absorbed, or diffused, causing the resultant color as seen. According to Taylor, the two dominant factors in producing small color differences are the thickness of the color layer and the background of the material.

In order to make a small color difference more easily detected, the illumination for inspection should be such that it accentuates the color difference as much as possible. For the best results, the luminant should radiate throughout the entire spectrum, but be rich in the spectral areas where the colored object has a maximum absorption, as small changes in these areas will often appreciably influence the color of the object and increase the contrast between the object and the defect.

The opposite of this is found in the color printing industry. Linsday (1949) says:

> When a colored material such as yellow printing ink which reflects everything but blue, is examined under its complementary color (blue) it absorbs this blue light and, therefore, looks dark or black. When the yellow proof, then, is examined under saturated blue light, the solid areas of yellow appear black against a bright background because the white background reflects most of the blue light which strikes it. The eye assumes that this high-brightness blue is essentially white, which gives a visual effect of black on white. Area on the proof where the yellow is not solid will appear as a gray value whose density depends upon the amount of pigment present. . . .

By varying this process through the three primary colored inks used in printing, the quality of the print can be checked. With the use of white illumination, the appearance of the final colored print can fully be checked.

Color Perception

> Color perception is what we see apart from variations in time and space. It does not refer to size, shape, texture, gloss, transparency, of flicker, though it is influenced by all of these. Color is what is immediately responsible for color perception. It is one aspect of the light entering our eyes (18).

It is a known fact that the eye adapts to a considerable extent to counteract changes in quality and quantity of different sources of illumination but its powers of adaptation are not unlimited according to Helson (1952). The state of adaptation along with the spectral distribution of energies reaching the eyes result in the color of the objects.

Evans (1949) reported that as a light source falls on a series of colored objects, each in succession, the observer sees each color as affected by the light source. It is impossible for the observer to predict the results of the next step from the color that he sees because he is dealing with a series of successive absorptions of energy. At each step the observer evaluates the resulting energy distribution and sees the resulting color, making it impossible to predict the color of the next step from the color seen. The only way that it can be done is to know the exact energy distribution of the source and the absorption properties of each colored object. In this respect Helson (1955) said that the spectral distribution needs to be considered only for special problems or situations.

It must be noted at this point that the main concern of the author is the effect of the various light sources on color perception and the color rendering properties of the light sources. The principles by which the eye sees and the theory of color vision are well established and many texts on the subject are available (See Reference Nos. 2, 7, 18, and 29).

Illumination and Color Perception

The spectral distribution of the energy radiated by a light source has a marked effect upon the color as seen by the eye. Helson (1955) said, "That the limits of color contrast are reached in everyday experience is shown by the fact that the color of objects do not remain constant in different illumination and when various conditions of viewing are changed. . . ." It is reported that as the illumination changes from daylight to a strongly chromatic illumination, objects and their color lose their individuality to a great extent and a single hue and mood prevail. The hue of any sample is a function of the relation of its reflectance to the adaption reflectance, which depends largely on the background. By its preponderating influence on the adaption level, the background can determine whether the object will be tinged with the illuminant hue, the contrasting hue, or be lost in saturation to the point of achromaticity.

Work with tungsten-light by Hunt (1950) led to the conclusion that marked changes of saturation occur on altering the adaptation conditions and leads to an explanation in terms of spilling over of responses of one color into the responses of another and fits into other visual and physiological phenomena.

Fluorescent lamps because of their wide range of colors present a slightly different problem in color rendition. Jerome (1953) reported that for the color of the test object to be properly rendered the fluorescent luminant must emit energy throughout the visible spectrum in order that the selectivity of the test object may properly alter the incident energy and cause proper color rendition in every wave band. He also said that the spectral energy distribution of a light is the only complete specification of its color rendering properties.

Effects of Illumination on Man

Illumination can affect man's performance and rate of fatigue.

Spectral quality of light cannot be neglected according to Simonson (1948) for it is as important as intensity and light distribution as a factor affecting visual performance and fatigue. It has been found that color effects on visual acuity is affected as the level of illumination changes.

One of the reasons for fatigue is reported by Weston (1954), who said that when lighting conditions are subnormal for the visual task, fatigue is accelerated mainly because of the undue mental exertion necessary for interpretation and discrimination.

"Deteriation of visual functions in the course of prolonged work is an important and objective criterion for visual fatigue . . . ," according to Simonson(1952). He also reported that visual fatigue is not an isolated process but affects the entire body.

Blackwell (1958) reported that in a detailed study on illumination for seeing, he determined that the eye sees, or "assimilates visual information" by bits, and that the level of illumination determines the number of assimilations that the average eye can make in one second. He stated that with sufficient illumination the eye can make ten assimilations per second, which he considers a conservative estimate of the maximum visual capacity with today's knowledge.

Another limiting factor is what Blackwell calls the "response limitation concept," which is made up of some sequence of input information, assimilation, and response. On this he said:

> Now, I believe this response limitations idea is very important because it does vary depending upon the task you are required to do. In ordinary reading for the fast reader there is no response limitation in my opinion. Instead you just let the information pour in and you get meaning from this impouring, highly complex informational input. Now, in certain assembly line jobs there is an obvious response limitation. You must do something about the information you extract and do it right then and there before you can extract more information. This puts a response limitation in the system. However, response limitations are not introduced as often as we might think. I use to work on an assembly line as a boy, picking peaches off a belt, and the way this was done, if you were any good at it, was that you didn't look at one peach, examine it, reach out and pick it off the belt if it wasn't any good. Instead, you let your eyes roam dynamically over the

> whole belt and when you spotted one that was bad you went on spotting others while you grabbed the bad peach while viewing it out of the corner of your eye. Thus, even in the case, which is somewhat response-limited, the situation is not as response limited as though one element of information were followed by one response. Instead information continues to come in and the responses are limiting to an extent, that is you can't get too far behind or you will miss the bad peaches altogether, but there is not an item-by-item response limitation.

According to Blackwell, the main contrast with which to be concerned is brightness contrast, as it is more important than color constrast. Usually all the color contrast available is worth less than 10 percent of brightness contrast.

Another factor affecting the level of illumination is the location of the center of the eye in relation to the target. Blackwell goes on to say that if the target is off center of the eye it is hard to detect but if it is in the center it is easy to detect. The center of the visual field of the eye is more sensitive than the other parts of the eye's visual field. One way to counteract this is to raise the illumination level of the entire field so that the outer regions of the eye's visual field have the required illumination for detection of the target.

Other Factors Affecting Grading Efficiency

Grading of apples and other fruits is a visual-manual operation in which the eye must detect the defective fruit and inform the brain, which in turn must activate the arm muscles into action to remove the defective fruit.

Other factors that must be considered, in addition to illumination, are speed of approach of the fruit, the direction of approach of the fruit, and the number of defects if the eye is to detect the defects and cause their removal.

In tests conducted by Malcolm and DeGarmo (1953) it was found that the best sorting efficiency was obtained when four rows of specimens, rotating at a rate of three times per foot of translation, and at a speed of three minutes per one thousand specimens, passed the worker. They found further that the side approach resulted in slower sorting speeds than did the direct approach. The difference in the percent of defective specimens to be removed had no effect on the sorting efficiency when the range of defects varied from 10 percent to 30 percent. When more than one type of defects were to be removed they found that slower sorting speeds resulted.

STUDY OF EXISTING APPLE PACKING PLANT LIGHTING

A study of apple packing plants in Western Michigan revealed a wide variation in lighting. There was no definite trend toward fluorescent lighting over tungsten filament lighting. Fifty percent of the twelve packing plants used fluorescent lamps over the grader, while 33 percent used incandescent filament lamps, and 17 percent used both. The reverse was true for general lighting of the packing room; 83.5 percent used filament lamps, 8.25 percent used fluorescent lamps, and 8.25 percent used none.

For detailed breakdown of this information and other survey data see Appendix II.

Grader Lighting

The size of lamp over the grader varied from 20 to 96 watts for fluorescent lamps and from 75 to 200 for filament lamps. As for color of fluorescent lamps, six graders used cool white, four white, one daylight, and one a non-standard color.

Nine of the installations surveyed used reflectors on all or part of the luminaires. Six fluorescent installations used industrial type fixtures which include reflectors. Of the filament lamp installations two used shallow dome reflectors and one used PAR-38 lamps.

The level of illumination at the critical grading areas varied widely. The level of illumination was not measured at each packing plant, but was estimated by the author to have ranged from a low of two or three footcandles to approximately 100 footcandles. While some plants had spots of higher intensities in the critical areas, none averaged higher than 100 footcandles.

General Lighting

The incandescent filament lamp size used for general lighting in the surveyed apple packing plants ranged from 40 to 200 watts. The fluorescent installation used a 96 watt lamp. One packing plant had no general lighting.

Four of the plants surveyed used no reflectors on the luminaires, three used shallow dome reflectors, three used RLM reflectors, and one plant with low ceilings used recessed fixtures.

The level of general illumination in the packing plants surveyed was estimated by the author to range from a low of no light to a maximum of five footcandles.

Color of Grader Belts

The color and reflectance of the background upon which the fruit is viewed affects the visibility of the defects. In the plants surveyed five used black belts, four used white belts, two used tan belts, and one used green belts. Nine of the graders surveyed used rubberized canvas belts; two used a plastic material; two used metal chains and one grader used both rubberized canvas belts and chain.

Packing Plant Construction

The reflectance of the surrounds, (walls, ceilings, and floors) affect the illumination in an apple packing plant because it determines the amount of general illumination that is reflected from the surrounds toward the object that it is desired to see. Also, the reflectance of the surrounds affects the rate of fatigue. A high or low reflectance can accelerate the rate of fatigue, while a medium reflectance retards the rate of fatigue.

Seven of the packing plants surveyed had cement or cinder block walls and five had glazed tile. Of the plants using blocks, four were left natural and the rest were painted, one each of white, silver, and green. Four packing plants with glazed tile walls were yellow and one was brown.

Six of the ceilings were constructed of wood, four of galvanized steel, one of plaster board, and one of building board. Four of the wooden ceilings were left natural and one was painted white. The ceilings constructed of other materials were all left natural.

PERCEPTIBILITY OF APPLES AND THEIR DEFECTS

This section is concerned with the perceptibility of red apples as distinguished from their surface defects. For the analysis of the perceptibility difference it is necessary to analyze the spectral reflectance curves of the apple surfaces and their surface defects.

Spectral Reflectance Curves

The spectral reflectance curves were obtained by measurement of the percent reflectance from the apple or defects surfaces by means of a spectrophotometer. Readings were obtained in 10 Mu. (Millimicron) increments from 400 to 720 Mu., the accepted range of vision for the human eye.

Ten spectral reflectance curves were obtained of the red surface, two each from McIntosh, Spy, Jonathan, Common Delicious, and Double Red Delicious. Seven curves were obtained of the green surface of the red apple, two each from McIntosh, Jonathan, and Common Delicious and one each from Double Red Delicious and Spy. Six curves were obtained of the defects on red apples. For the yellow variety, Golden Delicious, two curves were obtained of the yellow surface and one of the green surface. Data for all spectral reflectance curves is found in Appendix I.

For investigational purposes, averages of the normal and green surfaces were obtained by averaging the readings at each wavelength. The resultant averages were used as the average normal and green surface curves that are used in the determinations that follow.

The defective surfaces do not follow a pattern as does the normal and green surfaces. Furthermore, it is desired to investigate the effects of all surface defects and averaging would eliminate the high reflecting surfaces. Therefore the maximum reflectance of the six defect curves at each wavelength reading was used to plot the defective surface curve. This curve is called the maximum defective surface curve. Everything below the maximum defective surface curve is considered a defect.

Figure 2 shows the spectral reflectance curves for the average normal surfaces, average green surfaces, and the maximum defective surface.

Before analyzing the spectral reflectance curves, the spectral definition of the colors should be made. According to the General Electric Company (9) the accepted range of each color is:

Violet	400-430 Mu.
Blue	430-490
Green	490-560
Yellow	560-590
Orange	590-630
Red	630-720

The mature red apple contains very little color in the violet, blue, and green range. In the yellow range the amount of color starts increasing and continues the increase throughout the orange and red range to a maximum at the long wavelength end of the scale before passing beyond the visible range. The rise through this range is interrupted with a dip that bottoms at about 675 Mu. Norris (1958) explains that this dip is caused by a chlorophyll absorption band.

The spectral reflectance curves for the average yellow surface, the average green surfaces for the red and yellow varieties are similar to that of the average red surface, except that there is more color in the green and yellow areas.

The maximum defect spectral reflectance curve show that most of the defects are dark and contain little color.

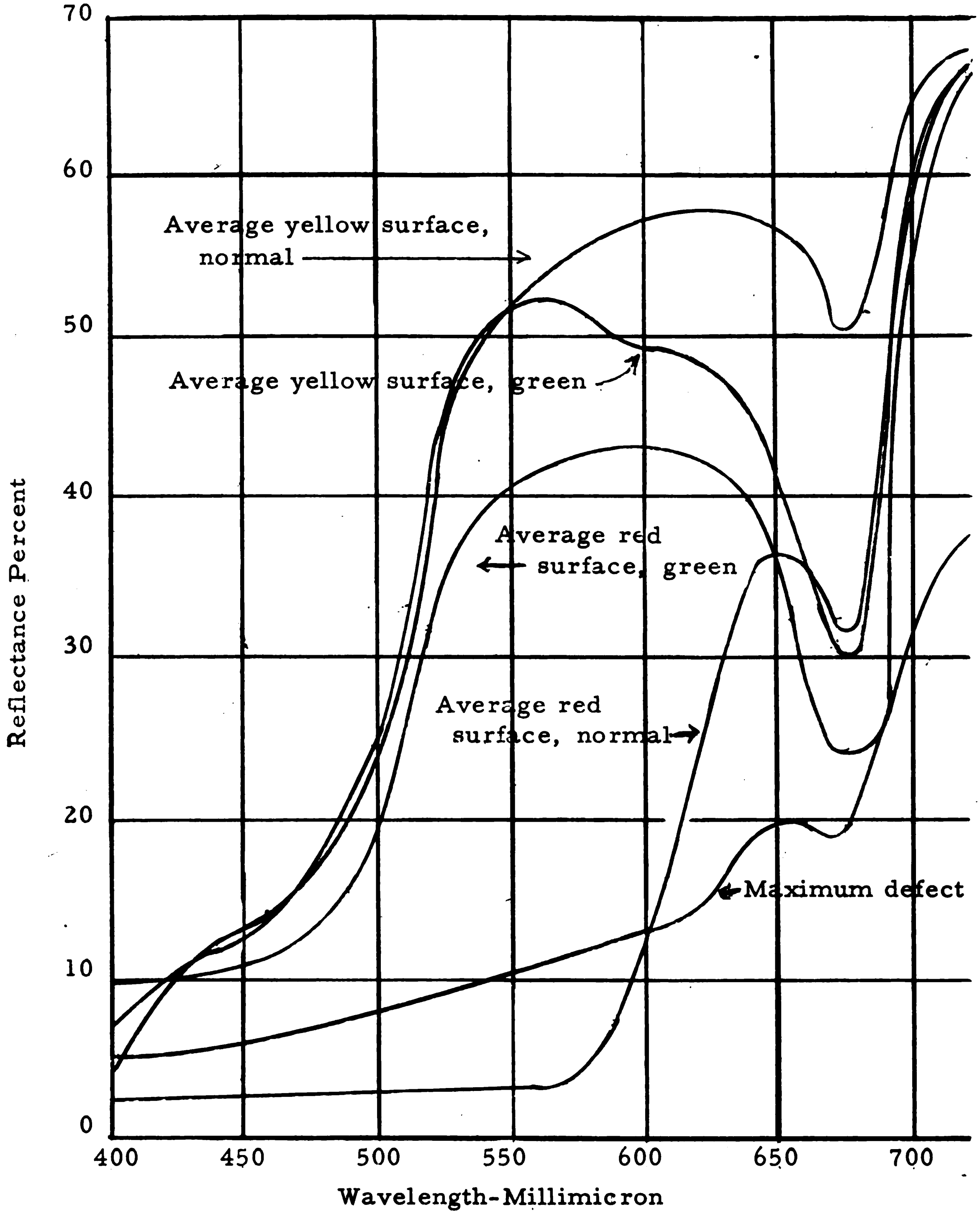


Figure 2. Average spectral reflectance curves for average normal and green apple surfaces and their maximum defects.

The analysis of the spectral reflectance curves reveals an observation more important than the color of the apple, the fact that the human eye does not see as does the spectrophotometer. The maximum sensitivity of the human eye occurs at 555 Mu. (Figure 3), and the spectrophotometer has no maximum sensitivity but sees all wavelengths with equal sensitivity.

Visibility Function

Since the human eye does not see as does the spectrophotometer, the next logical step was to obtain the spectral reflectance curves as seen by the human eye. This was obtained by multiplying, wavelength by wavelength, the eye sensitivity (luminosity function) by the spectral reflectance of the desired curve. The resulting curves, called visibility function, for the three red apple surfaces are shown in Figure 4.

Examination of the visibility function curves shows that instead of looking like the original spectral reflectance apple surface curves, the resulting curves look more like the luminosity curve with the exception of the visibility function curve of the red apple surface.

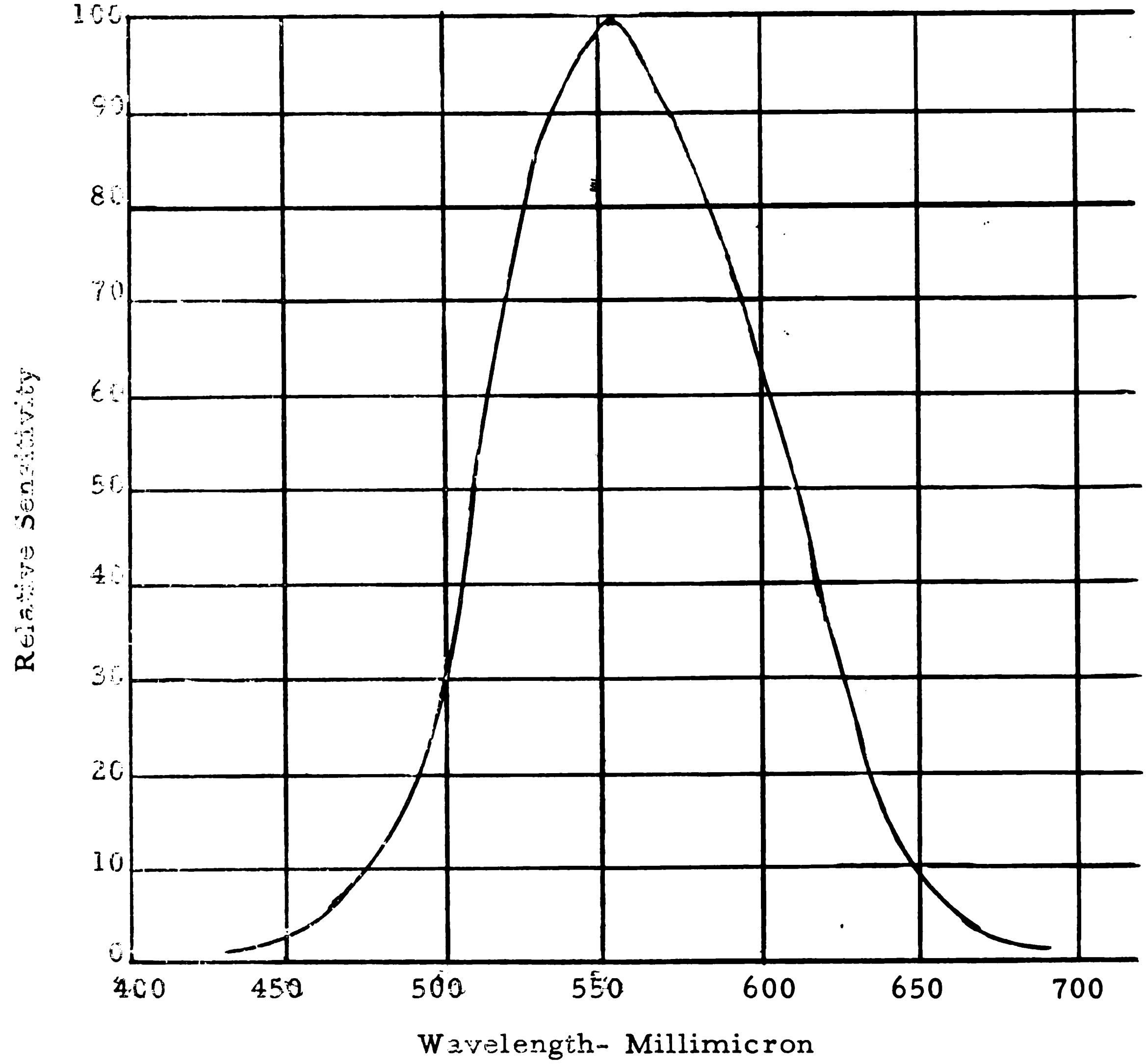


Figure 3. Relative spectral sensitivity for daylight adapted human eye.

Visibility Function

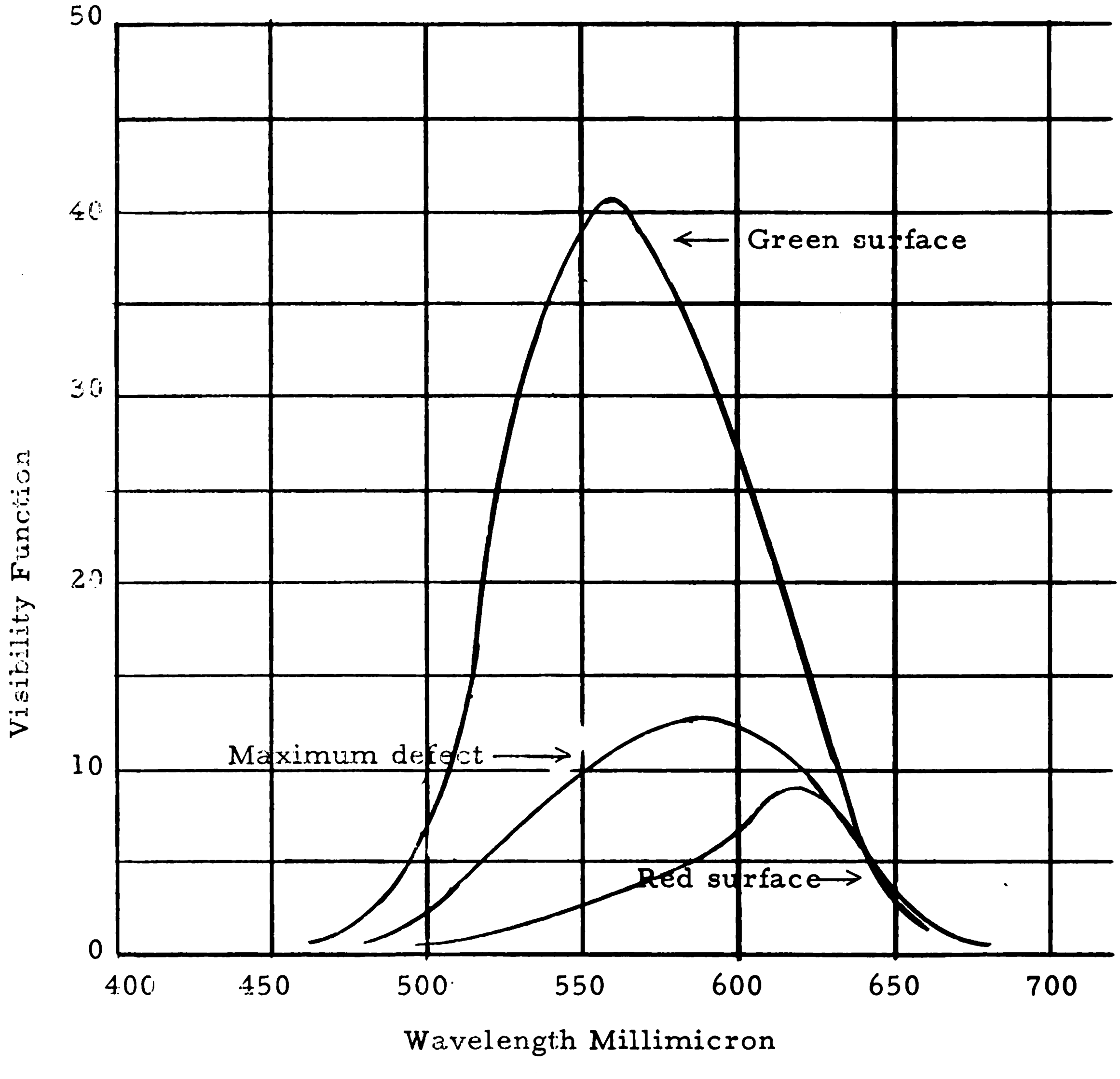


Figure 4. Average red apple and its defects as seen by the eye, visibility function.

DETERMINATION OF THE APPLE PACKING PLANT ILLUMINATION

The basic requirements of the desired luminant have been set forth in the preceding section. The objectives of this section are the determination of the proper luminant or luminants and the level of illumination for use in apple grading.

Contrast and Artificial Illumination

The worker on the grading line must see and remove the defective apples, with a minimum of effort and time. Thus the illumination must be such that it creates the maximum difference, or contrast, between the surface brightness of the desired apple surface and its defects.

To create the maximum contrast the luminant used in apple grading must be such that its predominant wavelengths occurs in the area of maximum contrast.

A study of luminant relative spectral energy distribution curves reveals that the various light sources have (a) different peak wavelengths, (b) different saturation, and (c) different amounts of energy radiated at the various wavelengths. For the relative energy distribution data of some typical luminants, see Appendix III.

In the determination of the proper luminant for use in apple grading, the relative values of the surfaces and contrasts, related to a common value, must be known. This makes it possible to properly weigh the relative merits of the three surfaces and the two contrasts under consideration. The maximum value of the average green surface, occurring at 560 Mu., was used as the value to which all of the curves are related. Figure 5 shows the relationships of the three apple surfaces under consideration. The relationship of the two contrast curves is shown in Figure 6. The contrast data is the mathematical difference between the visibility function curves of the two surfaces under consideration. It must be remembered that all of the values are for surfaces as viewed under an a achromatic luminant, that is, one that has the same relative values throughout the entire visible spectrum.

Since the least contrast occurs between the red surface and the maximum defect surface, the luminant used should favor this area more than the contrast between the red and green surfaces.

Selection of the Luminant

The selected luminant must emit energy throughout the entire visible spectrum yet be rich in the area of maximum contrast. Maximum contrast in the area of the red surface-maximum defect contrast is essential. A luminant that radiates a major portion of its energy in this region will give the maximum luminous flux (reflected spectral energy) in the desired area.

The maximum luminous flux results when the coefficient of correlation between the visibility function of the contrast curve and the visibility function of the light source energy curve is a maximum. The coefficient of correlation was determined by the equation for two variable correlation:

$$r = \frac{N\Sigma XY - (\Sigma X)(\Sigma Y)}{N\Sigma X^2 - (\Sigma X)^2 \quad N\Sigma Y^2 - (\Sigma Y)^2}$$

where r is the coefficient of correlation,

N is the number of pairs of variables,

X is the contrast between the apple surface and defect visibility functions

Y is the luminant energy visibility function.

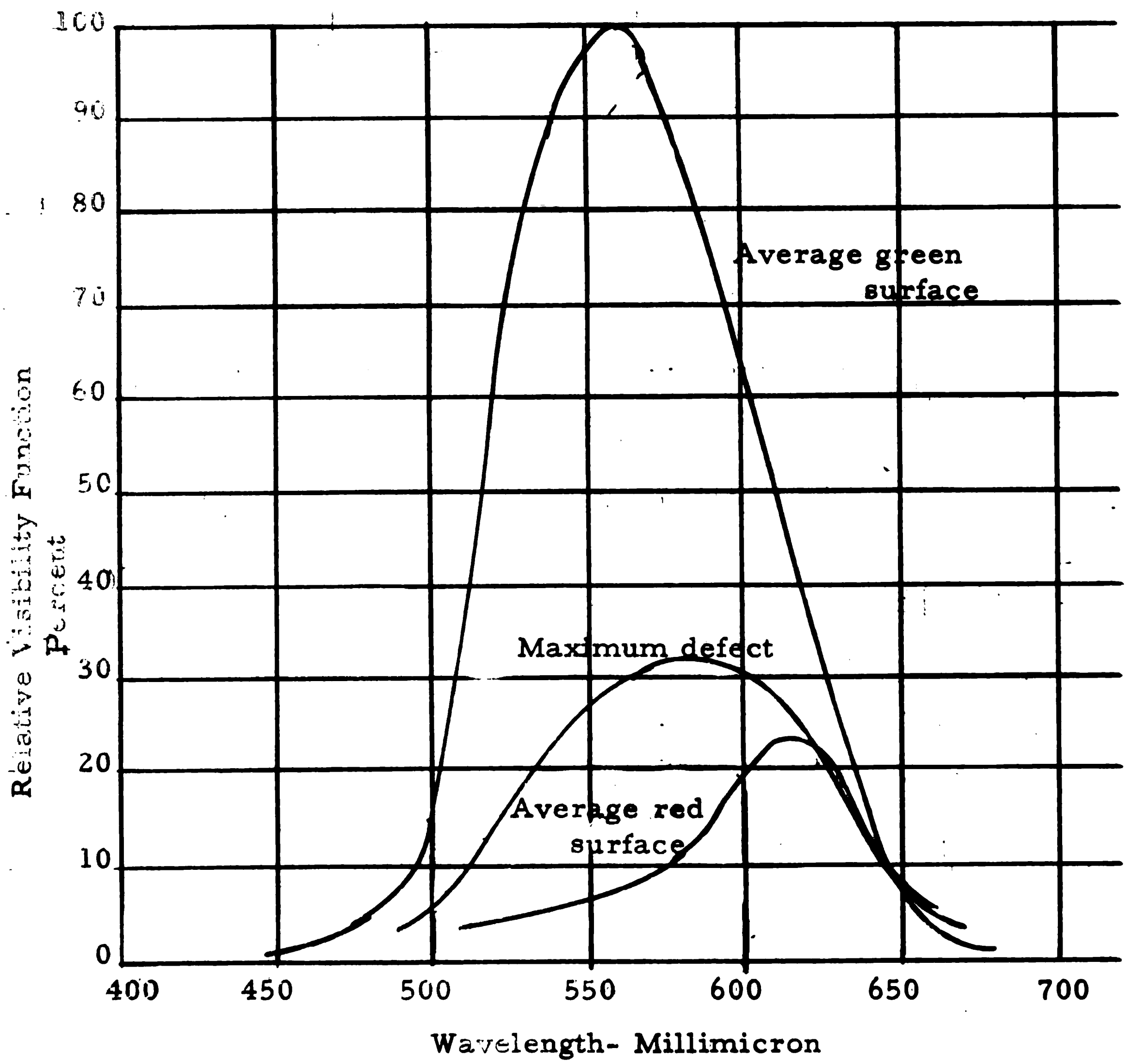


Figure 5. Relative visibility function of the red apple and its defects as related to the average green surface of the red apple.

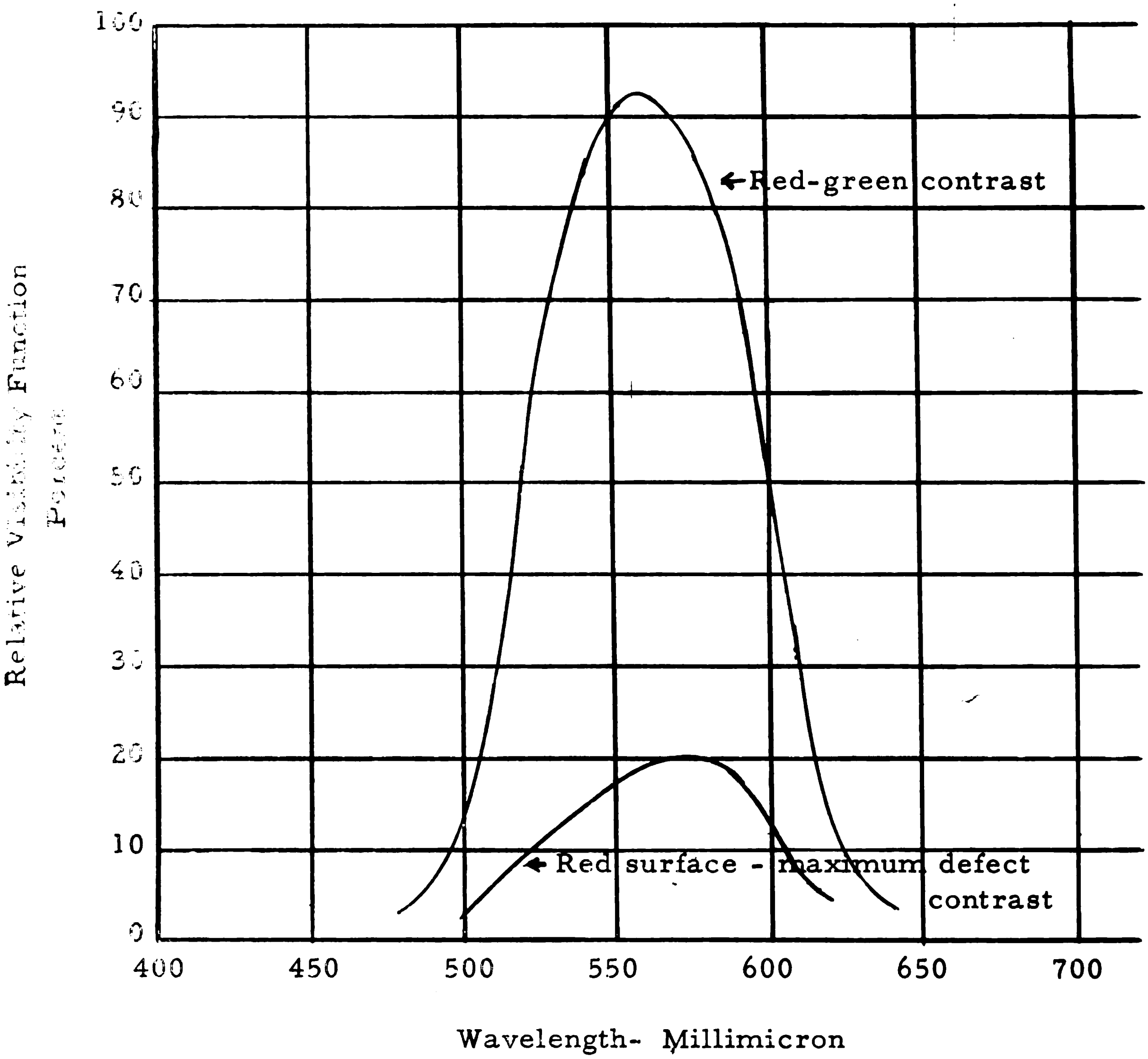


Figure 6. Relative visibility function of the contrast between the red apple and its defects as related to the visibility function of the average green surface.

The resulting coefficient of correlations are shown in Table II for the various luminants. The nonwhite fluorescent luminants cause undesirable psychological effects on the workers and can be eliminated.

The main lighting problem in grading of apples is the lighting of the least contrast, or that between the red surface and the maximum defect. The best coefficient of correlation was 0.96 and was obtained by using the deluxe cool white fluorescent lamp. Perfect correlation is 1.0. The deluxe cool white fluorescent lamp does not have the highest coefficient of correlation with the red-green contrast, but since the red-green contrast is relatively greater than the red surface-maximum defect contrast, the deluxe cool white fluorescent lamp is the one to use in grading apples.

The 150-watt incandescent filament lamp also is recommended for use in grading red apples because of high coefficient of correlation for the two red contrasts.

Since the yellow apple is relatively unimportant in Michigan as compared to the red varieties, it is recommended that the Michigan apple packing plants equip their graders with lighting as recommended for the red apple.

Laboratory Determination of the Luminant

In the previous section the selection of the proper luminant was discussed from the theoretical point of view. Observational laboratory investigations were conducted to test the theoretical conclusions before making trial installations in apple packing plants.

Under the illumination of the deluxe cool white fluorescent lamp apple samples appeared slightly duller in color than when viewed in natural daylight. The dark defects, such as limb bruise

TABLE II

COEFFICIENT OF CORRELATION FOR THE APPLE SURFACES AND THE VARIOUS LUMINANTS

Contrast	Luminant						
	Fluorescent						Incandescent
	Daylight	Deluxe cool white	Deluxe warm white	White	Cool white	Warm white	150-watt
Red-maximum defect	0.90	0.96	0.83	0.91	0.94	0.90	0.93
Red-green	0.86	0.85	0.82	0.88	0.87	0.80	0.88
Yellow-max. defect	0.90	0.83	0.65	0.76	0.84	0.75	0.65
Yellow-green	0.41	0.37	0.17	0.29	0.53	0.32	0.58

and worm damage appeared distinctly. The green surfaces appeared slightly yellow instead of green, but were readily visible.

The daylight fluorescent luminant caused the apple to appear dark. Green surfaces appeared very light, almost devoid of color. Dark defects were difficult to detect because of the dark appearance of the entire surface.

The deluxe warm white fluorescent luminant made the apple look more as it does in daylight, and the green surfaces were readily visible. However, the dark defects were harder to see as they assumed a red hue.

When the apple samples were viewed under the nonwhite fluorescent luminants, the results varied with the luminant. Under the pink fluorescent the dark defects stood out boldly on the red surface but the green surface all but disappeared. When viewed under the green luminant, the green surface stood out very distinctly on a dark background which the red surface assumed, and the dark defects were not visible. Under the blue fluorescent luminant, the red surface assumed a blue color. The green surface absorbed little of the blue color and was still visible. The dark defects were completely invisible.

When viewed under a 150-watt reflector type tungsten lamp the entire surface of the apple appeared much brighter than it did under fluorescent illumination, even though an attempt was made to provide the same level of illumination. The red surface appeared very bright and red, the green surface was readily visible, and the dark defects assumed a reddish hue.

After this series of laboratory investigations, there was little doubt but that the deluxe cool white fluorescent lamp was the proper fluorescent luminant for apple grading. The incandescent filament luminant was a good second source.

Determination of the Proper Illumination Level

Now that the desired luminants have been established, there remained the determination of the proper level of illumination. The level of illumination must be such that workers on the apple grading operation can easily and readily detect the defective fruit and remove it as it passes.

For lighting canneries the Illuminating Engineering Society (15) recommends a) that for 90 percent of the ability to see contrast, the human eye needs 20 footlamberts of product brightness, or adds also b) that to get 80 percent of the maximum visual acuity a product brightness of 25 footlamberts is needed.

The product brightness, or surface reflectance, of the apple surfaces was determined by the following equation (16):

$$R = \frac{\Sigma U_\lambda K_\lambda R_\lambda}{\Sigma U_\lambda K_\lambda}$$

where R is the desired product brightness,

U_λ is the relative energy of the luminant for wavelength λ.

K_λ is the eye sensitivity for wavelength λ.

R_λ is the reflectance as determined by the spectrophotometer for wavelength λ.

The resulting surface brightness of the various surfaces is shown in Table III.

From Table I it is found that the minimum amount of normal red surface is 50 percent for the maximum grade for the red varieties so the average of the red and green surfaces can be used to determine the surface brightness for use in determing the illumination requirements for grading red apples. This means that the average surface brightness is 23.4 percent. The minimum amount of yellow surface is 75 percent for the yellow varieties but since the surface brightness is higher than the average red surfaces and the recommendation is to equip the Michigan apple graders for red apples, the illumination level will not be determined as it is lower than for red apples.

To obtain 80 percent of the maximum visual acuity, or 25 footlamberts, the luminant must supply 107 footcandles of illumination, $\frac{25}{0.234} = 107$.

Due to the operating characteristics of lamps and the possibility of accumulating dirt on the lamp the determined light output must be increased by a service factor. The service factor varies because of the amounts of dirt in the area of the lamp, room

TABLE III

SURFACE BRIGHTNESS OF THE APPLE SURFACES UNDER DELUXE COOL WHITE FLUORESCENT AND 150-WATT INCANDESCENT FILAMENT ILLUMINATION

Surface		Luminant	
		Deluxe Cool White Fluorescent (percent)	150-Watt Incandescent (percent)
Red	normal	7.6	9.1
	green	39.2	38.9
Yellow	normal	51.0	55.8
	green	47.7	47.5
Maximum defect		11.2	11.5
Average	red	23.4	24.0
	yellow	49.4	51.6

conditions in which the lamp operates, and the operating conditions of the lamp. A medium duty service factor of 60 percent was selected.

This means that the luminant must supply 178 footcandles to fulfill the stated requirements necessary for proper vision in grading of red apples, $\frac{107}{0.6} = 178$. Therefore 178 footcandles of illumination on the apple surface is recommended when grading red apples.

General Packing Plant Illumination

The recommended 178 footcandles of illumination on the red apple surface in the critical apple grading areas is to be a combination of general and supplemental illumination. To minimize the eye strain of the workers the general illumination should be at least 10 percent of that of the supplemental illumination (15). This means that the general illumination should be at least 18 footcandles. Therefore 160 footcandles of supplemental illumination on the surface of the red apple is recommended for the grading operation.

A Practical Method of Determination of Grading Illumination

As the investigation into the required illumination for apple grading progressed, it became evident that there was a simplified, practical method of determining the required illumination. In fact, this simplified practical method will work for all grading and inspection work where detection of a different colored defect on a surface is required.

The first step in this method is to observe the desired surface and its defective surfaces luminated with the various luminants and determine which luminant gives the greatest contrast. This is the procedure that was followed in the laboratory investigations discussed earlier.

Once the desired luminant is determined, this luminant is used to determine the reflectance of the product. With the desired luminant radiating its energy onto the surface of the object, a light meter, placed about one foot from the object, measures the incident light and the product brightness (reflected light) (Figure 7). The ratio of the product brightness and the incident light gives the reflectance of the surface:

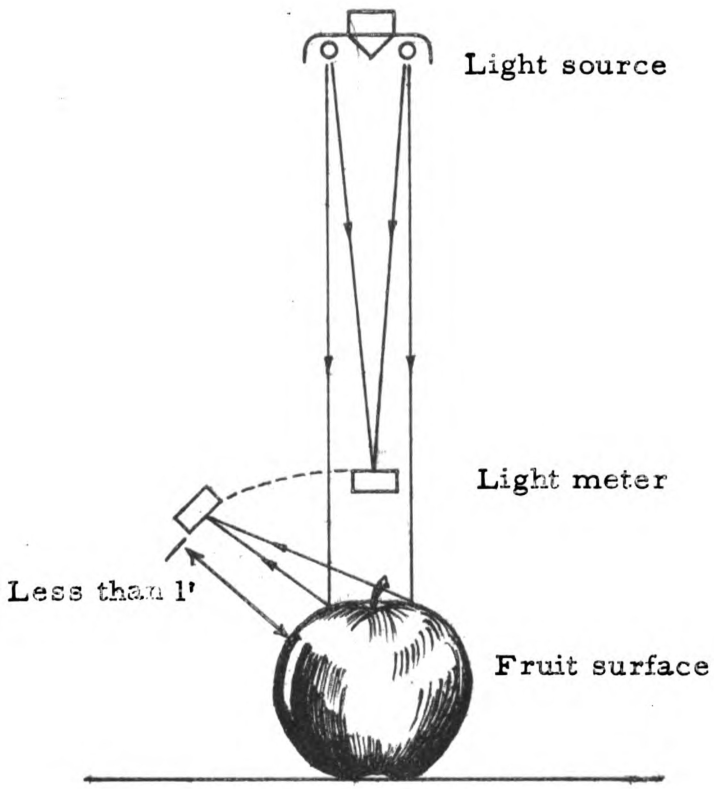


Figure 7. Light meter method of reflectance determination.

$$\frac{\text{Product Brightness}}{\text{Light onto Surface}} \times 100 = \text{Percent Reflectance.}$$

To obtain the desired level of illumination necessary to obtain 25 footlamberts of product brightness it is necessary to divide the 25 footlamberts by the reflectance and the service factor:

$$\frac{25}{(\text{Reflectance})\ (\text{Service Factor})} = \text{Required Level of Illumination.}$$

One advantage of this practical method is that all that is required is an assortment of luminants and a light meter to determine the luminant and the required level of illumination for any grading task; no spectrophotometer is needed.

Effects of the Background on Seeing

The effects of background on seeing was investigated in the laboratory using the selected luminants at the recommended level of illumination. These tests revealed that for maximum ease of detection of the defects, the background surrounding the apple should have a color and reflectance about equal to that of the apple. When this condition exists the apple appears to blend into the background, making the defect the main point of interest for the eye.

When the background was darker than the apple the main point of interest was the entire apple and the dark defects appeared to blend into the apple. At the same time the apple appeared darker than when viewed under a background similar in color to that of the apple. The green surface was readily visible under the dark background.

Viewing the apple on a background, lighter and with a higher reflectance than that of the apple, caused the apple to become the main point of interest and the defects, both dark and light, seemed to be less visible.

TEST LIGHTING INSTALLATIONS

The ideal commercially available luminant for use in apple sorting has been determined by theoretical and laboratory means. To prove the selection, actual lighting installations were made in apple packing plants. During the tests red apples were being sorted.

Tungsten Filament Lamps

Early in the investigation a packing plant manager with a new plant requested help in designing the lighting system. Since there was little available information at the time on the proper fluorescent color, it was decided to install 150-watt PAR-38 filament lamps because of their built-in reflectors. The lamps were mounted four feet apart and four feet above the working surface. This furnished approximately 250 footcandles of light on the working surface directly under the lamp and about 50 footcandles halfway between the lamps.

The workers commented on how much easier it was to see than before. The temporary system consisted of two bare 200-watt filament lamps mounted about 10 feet above the working surface. Talks with the workers revealed that there was no adverse heat problem and no reflected glare. The plant manager was so well satisfied that when deluxe cool white fluorescent lamps were suggested for part of the grading operation, he was not interested.

Fluorescent Lamps

Laboratory work with the fluorescent lamps revealed that the standard lamp would not produce sufficient light for apple grading. High output fluorescent lamps were selected as they produced the greatest amount of light of the desired color from among the various types of fluorescent lamps commercially available. In addition to the deluxe cool white lamps, daylight and deluxe warm white were obtained.

In some packing plants the fluorescent fixtures could not be installed at the proper height to obtain the desired level of illumination. These plants were packing the apples in cell packs. In order to provide the most convenient location for the cell dividers it was necessary to locate them over the grader. This meant that the luminaires had to be located higher then the desired three feet above the grader working surface. It was necessary to locate them about five feet above the working surface and this resulted in obtaining 130 footcandles of illumination instead of the desired 160 footcandles of supplementary illumination.

The owners and managers of the plants in which the fluorescent lights were installed were enthusiastic about the lamps and were unanimous in their selection of the deluxe cool white lamp as the one that gives the greatest contrast and ease of removal of defects. One owner said that now he was able to see and remove the scald on apples leaving controlled atmosphere storage, something he could not do when using other luminants. The workers reported less shadow and the defects were easier to see.

Results on Apple Quality

The packing plant owners and managers who cooperated were more concerned about quality of the apple pack than improved labor efficiency.

In all cases the manager or owner reported that the recommended lighting resulted in a better pack. The workers could see the defective fruit and remove it. This was readily noted by the increase in the amount of defective fruit removed during the day.

DESIGN OF THE ILLUMINATION SYSTEM

The illumination requirements have been determined for use in apple packing plants. The next step is to design an illumination system that will give the desired 178 footcandles of illumination on the working surface of the grader. At least 10 percent of this is to be provided in general illumination. The luminant to be used will be either the deluxe cool white fluorescent or the incandescent filament lamp.

The following installation details are based on the assumption that the walls of the packing plant are painted a neutral pastel color, having a reflectance of at least 30 percent, and that the ceiling is white or a neutral pastel.

It must be remembered that the recommendations in this report are minimums and additional illumination improves the visual efficiency.

The formula used, as well as much of the other technical information used in the development of the design procedure, was obtained from the Westinghouse Electric Corporation's Lighting Handbook.

General Illumination

The first step in the design of the general illumination system is to select the type of luminaires to be used, either industrial fluorescent luminaire or filament lamp equipped with RLM dome reflector. A reflector is a must to obtain the maximum efficiency from the lamp.

Next, the number of luminaires needed in the packing room is determined. This is determined by the following steps:

1. Determine the mounting height of the luminaire above the floor (Figure 8). Allow sufficient room for the fork lift truck to operate.

2. Divide the width of the packing room by the mounting height of the luminaire to determine the number of rows of luminaires needed. If the remainder is greater than one-third of the height, add another row.

3. Divide the length of the packing room by the mounting height of the luminaires to determine the number of luminaires in each row. If the remainder is over one-half of the mounting height, add another luminaire.

4. Multiply the number of rows by the number of luminaires in each row to determine the total number of luminaires.

5. Determine luminaire location as shown in Figure 9.

6. Determine the lamp size by the following equation:

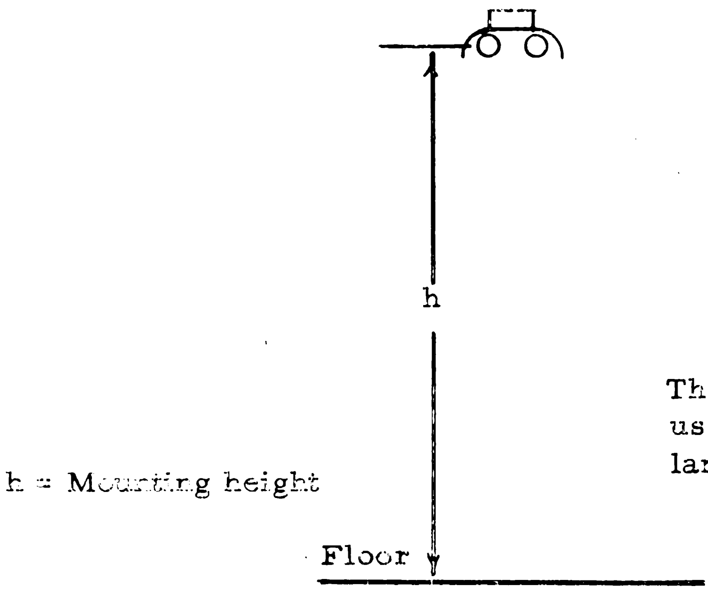
$$\frac{\text{Footcandles} \times \text{Area of Room}}{\text{Number of Lamps} \times 0.36} = \text{Lumens per Lamp}$$

where (1) Footcandles equals 18 in apple packing plants.

(2) Area of room is its length times its width.

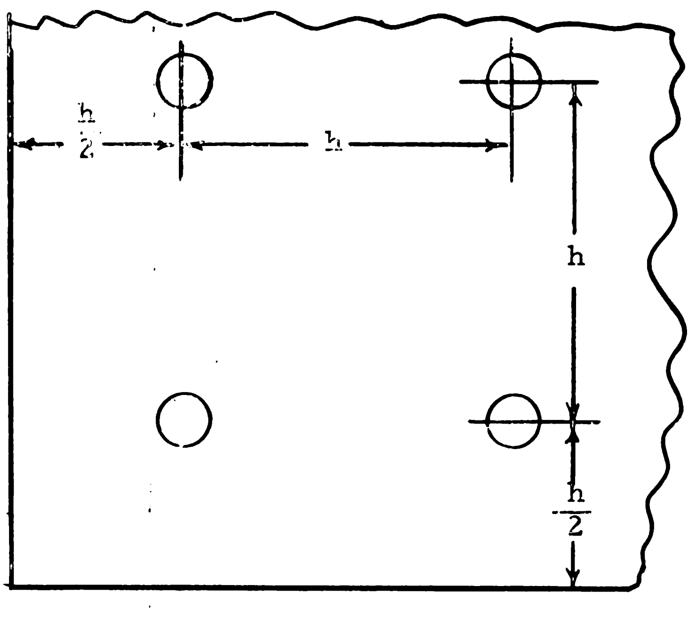
(3) Number of lamps equals the number of luminaires times the number of lamps per luminaire.

(4) 0.36 is a constant based upon the room size, lamp mounting height, and the reflectance of the walls, ceilings and floor as determined from an average of the packing plants surveyed and the service factor of the luminaires.



The same measurement is used for incandescent filament lamp and RLM reflector.

Figure 8. Mounting height of luminaire in packing room.



Fluorescent luminaires to be located the same as incandescent filament luminaires

Figure 9. Luminaire location in packing room.

(5) Lumens per Lamp is used to determine the lamp wattage. This is obtained from the latest manufacturer's lamp catalog. If the lumens are more than 10 percent greater than the nearest size, select the next larger size.

Supplemental Illumination

The supplemental illumination must provide 160 footcandles of shadowfree, glarefree illumination on the critical working surfaces. The critical surfaces are the dumping section, the pickout section and the packing section (Figure 1).

The incandescent filament luminaire over the grader should be mounted four feet above the working surface, with a spacing of three feet between the luminaires (Figure 10). Only 150-watt reflector type flood lamps are recommended. The type A incandescent lamp equipped with RLM dome reflector is not recommended because of its low efficiency as compared with the reflector type lamp.

The fluorescent luminaire should be of the industrial type, mounted in a continous row over the grader three feet above the working surface (Figure 11). The luminaires should be equipped with high output deluxe cool white fluorescent lamps.

In all cases the luminaires should be mounted over the center line of the grader. If obstacles prevent this, such as a defect removal belt, two rows of luminaires must be installed (Figure 12). These luminaires should be installed two feet from the center line on either side of the grader.

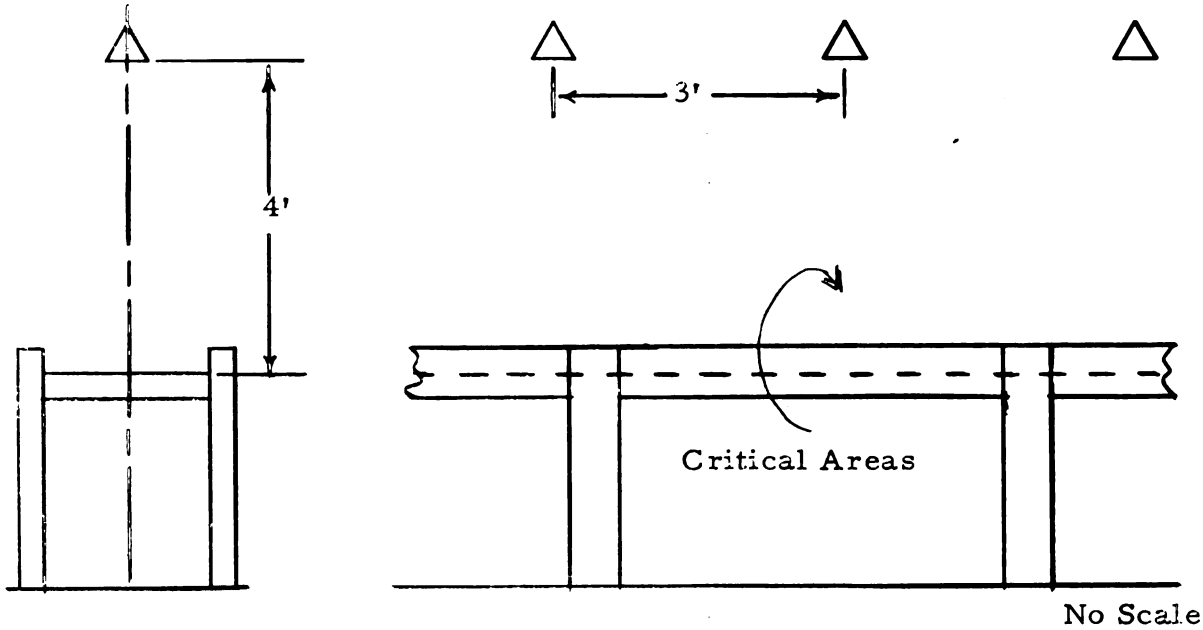


Figure 10. Location of incandescent filament luminaires over the apple grader.

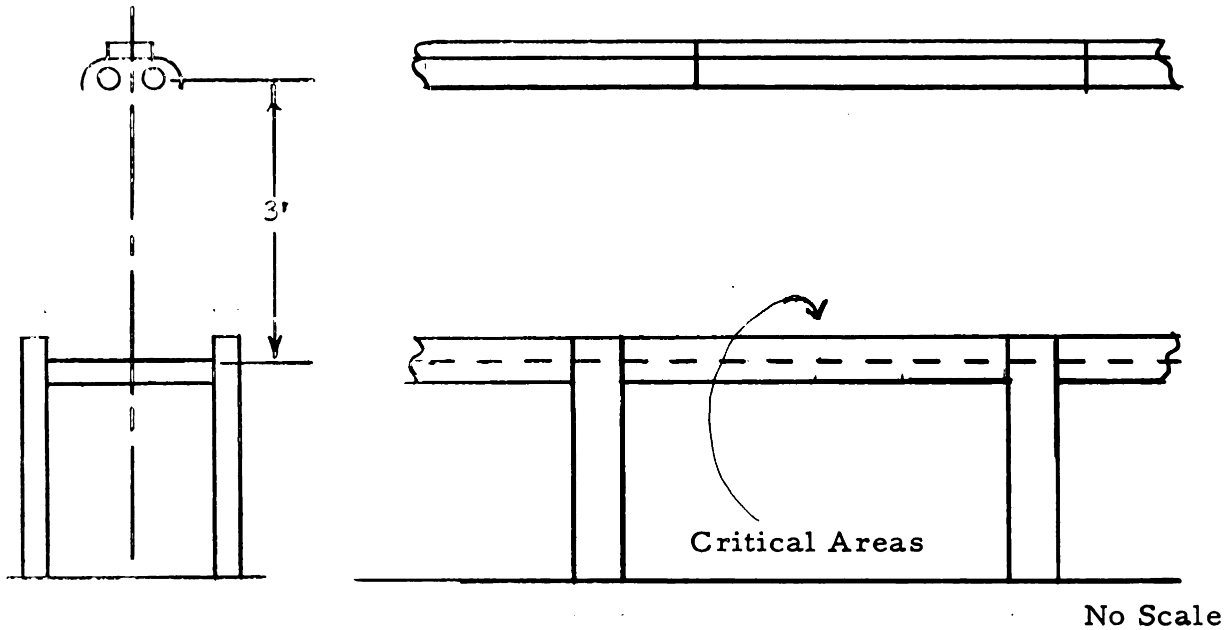


Figure 11. Location of fluorescent luminaires over the apple grader.

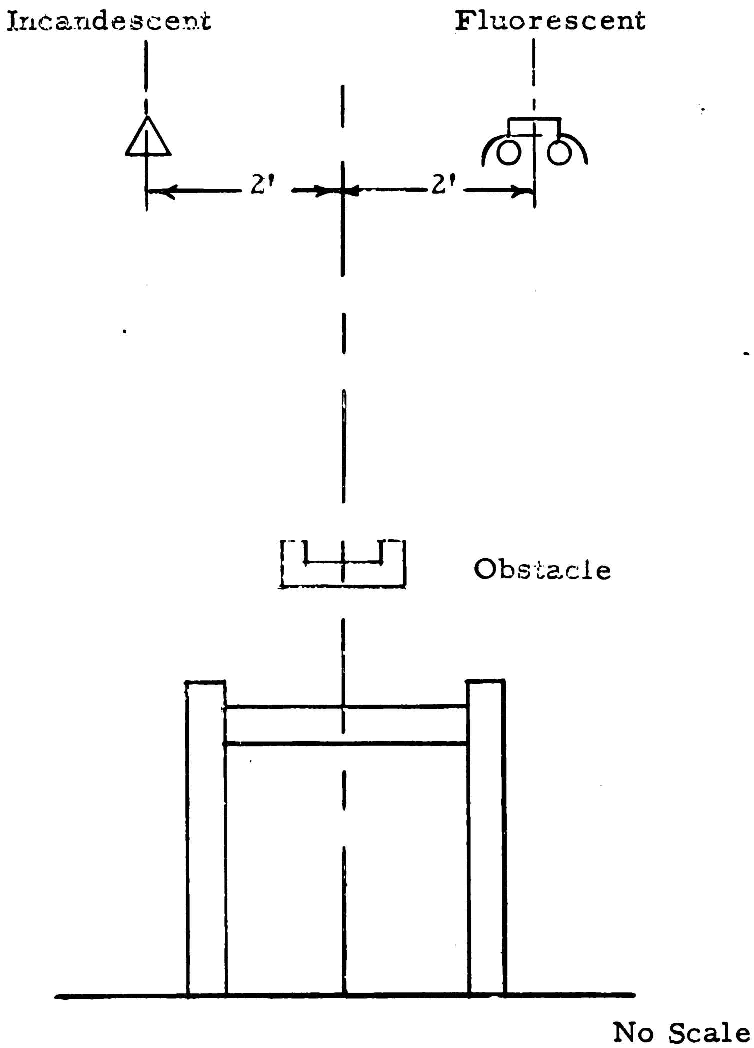


Figure 12. Location of luminaires when they cannot be located over the center of the grader.

SUMMARY AND CONCLUSIONS

Two of the problems the Michigan apple packer faces in the marketing of his fruit are increasing packaging costs and increasing demand for a better quality pack.

A survey revealed that many Michigan apple packing plants are hampered with poor lighting. Poor lighting makes it difficult for the worker to see the defective fruit and thereby affects adversely both the packaging costs and the quality of the pack.

Good lighting will help correct these adverse conditions. Good lighting means a more efficient worker and a better quality pack.

Good lighting in the packing plant is lighting of the proper quality and quantity. Light has proper quality when it accentuates the maximum contrast between the defect and the normal surface of the apple. Proper quantity of light is the level of illumination that will permit the worker to detect defective apples in the minimum of time.

The desired light source to use in grading apples must emit energy throughout the visible spectrum, and be rich in the area of maximum contrast between the defective and normal apple surfaces.

To select the proper light source, it is necessary to study first, the reflectance of the apple surfaces, and second, the relative energy distribution curves of the various light sources made available by the lamp manufacturers.

To determine the reflective properties of the apple surface, ten spectral reflectance curves of normal apple surfaces and seven of green surfaces were obtained with a Beckman spectrophotometer. Six curves of defects were obtained.

Averages of the normal and green surfaces for the red and yellow varieties were used in the determinations. Since it is desired to see all the defects, the maximum readings of the six defects at each wavelength were used. This curve is called the maximum defect curve.

An interesting and important observation was noted from these reflectance curves. The yellow apple is redder according to the spectrophotometer than is the red apple. The spectrophotometer has equal sensitivity throughout the entire visible spectrum, while the human eye's sensitivity reaches a maximum at 555 Mu. and approaches zero at either end of the visible spectrum.

The visibility function, or the spectral reflectance curve as the eye sees it under achromatic light, was arrived at by multiplying, wavelength by wavelength, the spectral reflectance curve by the luminosity function (eye sensitivity curve).

The contrast between the normal surface and the green surface or the defective surface is the mathematical difference between the visibility function curves of the two surfaces. The least contrast was the contrast between the normal red surface and the maximum defect as determined by relating the contrast curves to a common factor. A light source that radiates the major portion of its energy in the region of maximum contrast will give the maximum luminous flux (reflected spectral energy) in the desired areas.

The maximum luminous flux results when the coefficient of correlation for a two-variable correlation, between the contrast curve and the visibility function of the light source energy curve is a maximum.

Of the "white" fluorescent lamps, the deluxe cool white lamp had the best correlation (0.96) for the correlation between the least contrast and the light sources. Perfect correlation is 1.0. The 150-watt incandescent filament lamp with a correlation of 0.93 was acceptable.

Observational tests were performed in the laboratory to verify the results of the theoretical conclusions. The nonwhite fluorescent lamps cause undesirable psychological effects on the worker making these lamps of little value in the grading of apples.

Of the more desirable "white" fluorescent lamps the deluxe cool white lamp increases the visibility of the defect because the defects do not take on the red hue they do under the deluxe warm white lamp. The daylight lamp darkens the entire red surface and causes the dark defects to be difficult to detect. The green surface was readily visible under these lamps.

The incandescent filament lamp causes dark defects to take on a reddish hue. The green surface is readily visible.

The deluxe cool white fluorescent lamp was considered the best for apple sorting. The 150-watt incandescent filament lamp is acceptable.

The apple, when viewed on a similar colored background, tends to blend into the background and the defect becomes the main point of interest for the eye. When viewed on a background darker or lighter than the apple, the apple itself became the main point of interest of the eye and the defect becomes harder to see.

A simplified practical method was developed to determine the lighting requirements for the apple grading areas, as well as for any other type of grading or sorting where it is desired to detect a defect on a normal surface. The equipment consists of a light meter, an assortment of light sources, and lighting fixtures. The procedure consists of viewing the apple and its defects under the various light sources and determining the one that gives the maximum contrast between the defect and the normal surface. Then using the selected light source, measure the incident light and the product brightness of the apple surface with a light meter. The light meter should be held as close as possible to the normal surface, preferably no further away than one foot. The ratio of the two readings gives the reflectance of the surface.

A product brightness of 25 footlamberts is needed to obtain 80 percent of maximum visual acuity and will give more than 90 percent of maximum ability to see contrast.

The average product brightness of the red apple under the deluxe cool white fluorescent lamp was 23.4 percent and 24 percent under 150-watt incandescent filament lamp. To obtain 25 footlamberts of product brightness 178 footcandles of lamp output on the surface of the apple is needed when a medium duty service factor of 60 percent is introduced. The same recommendation was made for yellow varieties, even though they can use less light because of higher reflectance, because of the relative unimportance of the yellow apple in Michigan.

The 178 footcandles of light is to be provided by a combination of general packing plant lighting and supplemental lighting over the critical areas. To provide light that will cause a minimum of eye strain, the general illumination should be at least 10 percent of the total requirement. For the red apples the general lighting should be at least 18 footcandles and the supplementary lighting 160 footcandles.

The design procedure for designing the general lighting system was developed. The supplemental lighting for apple grading should provide a shadowfree, glarefree light on the working surface, and be of sufficient intensity to provide the required product brightness. For apple grading, fluorescent luminaires should be mounted in a continuous row over the critical areas and at a height of three feet above the working surface. The fluorescent luminaires are to be equipped with high output deluxe cool white lamps to obtain the required footcandle level. Incandescent filament lamps should be mounted four feet above the working surface and spaced three feet apart. In all cases, the luminaires should be mounted over the center line of the working surface if possible. If obstacles prevent this, two rows of luminaires must be installed. These luminaires should be installed two feet from either side of center line of the grader.

The deluxe cool white fluorescent lamp was the unanimous choice of the west Michigan apple packing plant owners and managers in whose plants test installations were made. After comparing the results obtained with several fluorescent lamp colors they all selected the deluxe cool white fluorescent lamp. The manager of the plant in which the 150-watt incandescent filament reflector type lamp was installed was well satisfied with the results.

APPENDICES

APPENDIX I

SPECTRAL REFLECTANCE CURVES

The spectral reflectance curves used in this investigation were obtained with a Beckman Model DU spectrophotometer, which is owned by the Michigan State Highway Department and is located in their research laboratory on Michigan State University campus. This instrument is equipped with a Model 2580 reflectance attachment. Standard operating procedure was followed (3).

For a standard, magnesium carbonate was used and the resulting readings were corrected to a certified magnesium oxide block. The correction factors are shown in Table IV. Since the certified block was calibrated in 20 Mu. increments and the readings were taken every 10 Mu., the correction factors were interpolated for the intermediate figures.

The sample consisted of a slab of apple of sufficient size to completely fill the opening in the sample drawer. At least one-eighth of an inch of flesh was left under the epidermal layer so as to detect any color reflectance that might come from the flesh. An attempt was made to get the sample to lie flat without wrinkling of the surface. The slight curvature that remained was not felt to have affected the results as the instruction book (3) says that samples with diameters as small as one inch can be used. All samples used had a diameter greater than one inch.

The readings were taken every 10 Mu. throughout the entire length of the accepted visible spectrum, from 400 to 720 Mu.

The corrected reflectances for all varieties measured and the defects measure are found in Tables V through VIII. Table IX gives the average readings used in all calculations in the investigation.

TABLE IV

CORRECTION FACTORS FOR USE IN CONVERTING MAGNESIUM CARBONATE STANDARD BLOCK TO A CERTIFIED MAGNESIUM OXIDE STANDARD

Wavelength Mu.	Correction Factor
400	0.911
410	0.917*
420	0.922
430	0.928*
440	0.934
450	0.935*
460	0.936
470	0.942*
480	0.948
490	0.950*
500	0.951
510	0.954*
520	0.957
530	0.960*
540	0.962
550	0.964*
560	0.966
570	0.969*
580	0.973
590	0.973*
600	0.973
610	0.975*
620	0.976
630	0.978*
640	0.980
650	0.980*
660	0.980
670	0.980*
680	0.979
690	0.981*
700	0.983
710	0.983*
720	0.983*

*Interpolated values

TABLE V

CORRECTED SPECTRAL REFLECTANCE READINGS FOR TYPICAL McINTOSH AND DOUBLE RED DELICIOUS SURFACES

Variety	McIntosh				Double Red Delicious		
Sample No.	1	2*	3	4*	1	2*	3
Wave-length Mu.	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
400	1.79	12.7	1.41	6.95	2.04	2.64	2.39
410	1.81	13.2	1.65	8.20	2.05	2.66	2.40
420	1.93	13.7	1.80	9.18	2.06	2.68	2.60
430	2.55	13.3	2.05	9.28	2.37	2.87	2.70
440	3.00	13.6	2.26	9.44	2.65	2.89	2.72
450	3.12	15.2	2.36	11.0	2.68	2.90	2.64
460	3.20	16.8	2.36	12.2	2.64	2.90	2.62
470	3.09	16.9	2.31	12.4	2.68	2.92	2.54
480	2.84	17.1	2.01	12.8	2.47	2.88	2.46
490	2.78	18.8	1.92	13.7	2.42	2.76	2.38
500	2.58	18.5	1.84	16.7	2.39	2.76	2.28
510	2.43	24.0	1.81	22.4	2.41	2.69	2.20
520	2.29	32.6	1.62	29.6	2.26	2.59	2.20
530	2.20	48.4	1.63	33.6	2.19	2.60	2.11
540	2.10	51.0	1.64	34.6	2.20	2.60	2.21
550	2.07	52.0	1.64	35.6	2.21	2.56	2.22
560	2.12	52.5	1.64	36.7	2.38	2.51	2.22
570	2.41	50.3	1.65	37.3	2.48	2.64	2.42
580	3.30	48.2	1.99	37.4	3.09	3.11	3.02
590	5.84	46.5	3.20	38.0	4.73	4.16	4.38
600	11.8	46.0	6.80	39.0	8.10	7.30	7.69
610	18.7	44.8	12.3	38.0	13.6	11.3	11.3
620	25.5	42.8	17.8	36.7	19.2	13.6	16.2
630	30.8	42.9	25.2	36.2	25.4	21.4	22.4
640	33.9	41.0	29.4	33.8	29.2	25.4	26.2
650	33.0	35.3	30.4	28.8	30.1	27.0	28.5
660	29.4	30.4	28.4	24.5	28.8	26.4	28.5
670	24.5	24.3	24.0	18.3	25.5	22.4	25.5
680	25.0	25.4	25.4	18.6	27.0	24.0	26.6
690	39.2	41.0	40.2	32.4	40.6	33.2	40.6
700	57.0	58.1	56.0	52.5	55.5	51.5	55.2
710	64.9	66.2	63.5	62.1	63.6	59.4	62.1
720	67.8	69.6	66.0	67.3	66.7	62.9	65.6

*Green Surfaces

TABLE VI

CORRECTED SPECTRAL REFLECTANCE READINGS FOR TYPICAL COMMON DELICIOUS AND SPY SURFACE

Variety	Common Delicious				Spy		
Sample No.	1*	1*	3	4	1*	2	3
Wave-length Mu	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
400	11.4	8.92	3.10	2.91	4.20	2.37	3.08
410	12.8	9.90	3.21	3.26	4.81	2.39	3.47
420	12.9	9.45	3.22	3.87	5.36	2.77	4.32
430	12.5	10.0	3.14	4.46	5.92	3.56	5.10
440	13.1	10.3	3.18	4.75	6.22	4.16	5.36
450	14.5	11.4	2.90	4.65	6.77	4.35	5.37
460	15.1	13.1	2.90	4.77	7.30	4.42	5.39
470	17.0	13.9	2.82	4.80	7.35	4.45	5.18
480	16.3	13.4	2.46	4.43	7.10	4.16	4.74
490	18.2	15.4	2.56	4.41	7.35	3.99	4.55
500	21.8	21.0	2.57	4.61	8.65	3.88	4.46
510	30.7	29.0	2.58	4.76	11.0	3.72	4.39
520	37.3	37.1	2.58	4.78	14.3	3.54	4.20
530	41.3	42.0	2.59	4.90	16.3	3.44	4.22
540	43.1	44.3	2.60	4.97	17.3	3.33	4.23
550	44.5	44.8	2.82	5.21	18.3	3.34	4.45
560	45.4	45.2	3.28	5.90	19.3	3.58	5.04
570	46.3	44.5	4.35	7.45	20.3	4.16	6.66
580	46.6	43.1	6.40	10.2	21.4	5.50	9.64
590	46.6	41.8	9.82	14.9	22.4	8.55	15.0
600	47.9	42.0	15.8	22.0	24.7	14.5	22.6
610	47.7	41.5	21.2	28.5	25.0	19.5	30.0
620	46.1	39.1	27.6	35.2	23.8	24.2	36.6
630	46.5	38.6	34.3	41.0	23.9	28.4	41.4
640	44.0	36.4	40.0	45.6	22.3	29.3	44.0
650	39.7	32.4	43.3	48.1	19.1	27.4	43.0
660	34.8	27.6	44.2	47.0	15.7	24.5	40.1
670	28.4	21.8	42.3	43.2	12.3	20.1	35.6
680	28.2	22.0	43.9	42.8	12.7	20.6	37.0
690	43.1	34.9	53.8	51.2	21.6	33.4	48.5
700	58.9	51.0	62.9	60.6	38.6	50.0	60.0
710	65.0	59.0	66.8	64.9	52.0	59.4	64.4
720	68.0	62.5	68.2	66.0	59.7	63.8	66.4

*Green Surfaces

TABLE VII

CORRECTED SPECTRAL REFLECTANCE READINGS FOR TYPICAL JONATHAN AND GOLDEN DELICIOUS SURFACES

Variety	Jonathan				Golden Delicious		
Sample No.	1	2	3*	4*	1	2	3*
Wave-length Mu.	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
400	2.32	2.56	11.3	11.8	4.30	4.82	7.10
410	2.44	2.57	11.9	13.6	6.00	6.68	8.66
420	2.60	2.58	11.9	13.7	8.43	8.39	10.1
430	2.62	2.68	11.2	13.3	11.1	10.6	11.1
440	2.56	2.72	11.7	13.8	13.0	12.1	11.9
450	2.52	2.70	13.4	14.0	13.5	12.1	12.7
460	2.53	2.66	15.4	15.9	15.1	13.3	14.6
470	2.45	2.56	16.0	16.1	16.9	15.1	15.6
480	2.27	2.52	15.3	15.6	15.9	14.0	15.1
490	2.18	2.47	17.6	17.1	18.2	16.2	17.1
500	2.18	2.48	24.6	22.3	25.9	23.6	24.6
510	2.14	2.28	33.4	28.2	34.9	31.4	33.4
520	2.10	2.25	42.0	32.7	43.2	39.0	42.5
530	2.09	2.22	46.8	34.9	48.9	44.4	48.0
540	2.08	2.22	47.3	36.6	52.1	48.0	50.5
550	2.12	2.23	49.0	38.8	53.8	49.9	52.0
560	2.22	2.23	50.0	41.3	54.8	51.1	52.2
570	2.71	2.32	51.3	44.5	56.0	53.0	52.0
580	3.84	2.72	51.5	47.5	57.0	54.3	51.0
590	6.68	4.18	51.4	51.4	56.5	55.3	49.5
600	12.0	8.67	51.9	52.1	57.5	56.5	49.5
610	18.1	14.5	51.4	52.7	58.0	57.5	49.0
620	24.4	22.4	49.7	52.0	58.0	58.5	47.9
630	31.2	31.8	49.6	52.7	58.1	58.7	47.6
640	35.6	39.2	47.0	50.4	57.9	58.9	45.0
650	37.2	44.2	42.3	46.0	56.0	57.8	41.3
660	36.8	46.5	36.4	41.1	53.2	56.0	36.8
670	34.3	46.3	29.8	35.1	49.0	53.0	30.4
680	37.0	48.7	30.3	35.7	49.4	53.0	31.2
690	50.9	59.1	45.6	50.0	57.8	59.6	44.9
700	62.5	67.0	62.0	63.1	65.4	63.0	59.2
710	67.3	70.0	68.3	68.0	66.8	65.6	64.9
720	69.0	71.3	70.2	70.1	68.5	66.2	67.0

*Green Surface

TABLE VIII

CORRECTED SPECTRAL REFLECTANCE READINGS FOR TYPICAL APPLE SURFACE DEFECTS

	Sample Number					
	1	2	3	4	5	6
Wave-length Mu.	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent	Per Cent
400	4.27	3.64	2.32	3.94	3.19	4.90
410	4.44	3.65	2.80	3.95	3.20	5.18
420	4.52	3.69	3.14	3.97	3.30	5.45
430	4.54	3.66	3.24	4.11	3.32	5.56
440	4.57	3.68	3.26	4.20	3.44	5.83
450	4.58	3.36	3.27	4.15	3.46	6.05
460	4.80	3.37	3.23	4.16	3.56	6.20
470	4.90	3.44	3.25	4.33	3.58	6.54
480	5.12	4.55	3.12	4.48	3.66	6.76
490	5.45	4.57	3.02	4.56	3.67	7.08
500	5.80	4.61	3.04	4.86	3.79	7.48
510	6.18	4.62	3.04	5.14	3.90	7.85
520	6.72	4.59	2.96	5.65	3.92	8.31
530	7.46	4.61	2.98	6.20	4.09	8.82
540	8.29	4.61	2.98	6.80	4.18	9.29
550	9.41	4.54	3.13	7.45	4.34	9.93
560	10.6	4.94	3.38	8.13	4.45	10.5
570	12.6	5.41	3.86	8.91	4.46	11.0
580	14.6	6.03	4.88	9.70	4.65	11.7
590	17.4	6.70	6.42	10.4	4.69	12.4
600	20.0	7.50	9.05	11.3	4.92	12.8
610	22.9	8.65	11.8	12.0	5.15	13.6
620	25.8	10.2	14.4	12.9	5.46	14.5
630	28.8	11.9	16.8	13.7	5.95	15.2
640	31.6	13.6	18.6	13.9	6.22	15.7
650	34.2	15.2	19.6	13.9	6.63	16.3
660	36.2	15.8	19.6	13.7	7.10	16.6
670	38.2	16.8	19.0	12.8	7.64	16.6
680	40.1	18.9	19.9	13.8	8.14	16.8
690	42.3	22.8	26.3	17.8	8.65	18.7
700	44.2	26.0	31.8	21.8	9.40	20.6
710	45.7	28.4	35.2	24.4	9.94	21.6
720	46.4	30.2	37.8	25.6	10.5	22.7

Sample No. 1 Rot on McIntosh
2 Rot on McIntosh
3 Bruise on McIntosh
4 Limb bruise on Jonathan
5 Worm on McIntosh
6 Scab on McIntosh

TABLE IX

AVERAGE CORRECTED SPECTRAL REFLECTANCE READINGS FOR TYPICAL AVERAGE APPLE SURFACE AND MAXIMUM DEFECT READINGS

	Average Red Varieties		Average Yellow Variety		
Wave-length Mu.	Red surface Per Cent	Green surface Per Cent	Yellow surface Per Cent	Green surface Per Cent	Max. defect Per Cent
400	2.42	9.61	4.56	7.10	4.90
410	2.55	10.63	6.34	8.66	5.18
420	2.77	10.95	8.41	10.1	5.45
430	3.10	10.78	11.15	11.1	5.56
440	3.33	11.16	12.55	11.9	5.83
450	3.33	12.32	12.80	12.7	6.05
460	3.57	13.82	14.20	14.6	6.20
470	3.52	14.23	16.00	15.6	6.54
480	3.34	13.94	14.95	15.1	6.76
490	2.97	15.45	17.20	17.1	7.08
500	2.93	19.36	24.75	24.6	7.48
510	2.87	25.50	33.15	33.4	7.85
520	2.78	32.22	41.10	42.5	8.31
530	2.76	37.60	46.65	48.0	8.82
540	2.75	39.17	50.05	50.5	9.29
550	2.83	40.40	51.85	52.0	9.93
560	3.06	41.48	52.95	52.2	10.6
570	3.66	42.07	54.50	52.0	12.6
580	5.07	42.24	55.15	51.0	14.6
590	7.73	42.58	55.80	49.5	17.4
600	13.02	43.37	57.00	49.5	20.0
610	14.84	43.01	57.80	49.0	22.0
620	25.06	41.45	58.25	47.9	25.8
630	31.18	41.39	58.40	47.6	28.8
640	35.22	39.27	58.40	45.0	31.6
650	36.52	34.80	57.90	41.3	34.2
660	35.40	30.07	55.15	36.8	36.2
670	32.13	24.28	51.00	30.4	38.2
680	33.25	24.78	51.20	31.2	40.1
690	47.96	38.37	58.70	44.9	42.3
700	58.70	54.84	64.65	59.2	44.2
710	64.66	62.94	66.25	64.9	45.7
720	66.94	66.77	67.90	67.0	46.4

Figure 13 shows the spectral reflectance curves for one variety, McIntosh. Data from Table V was used.

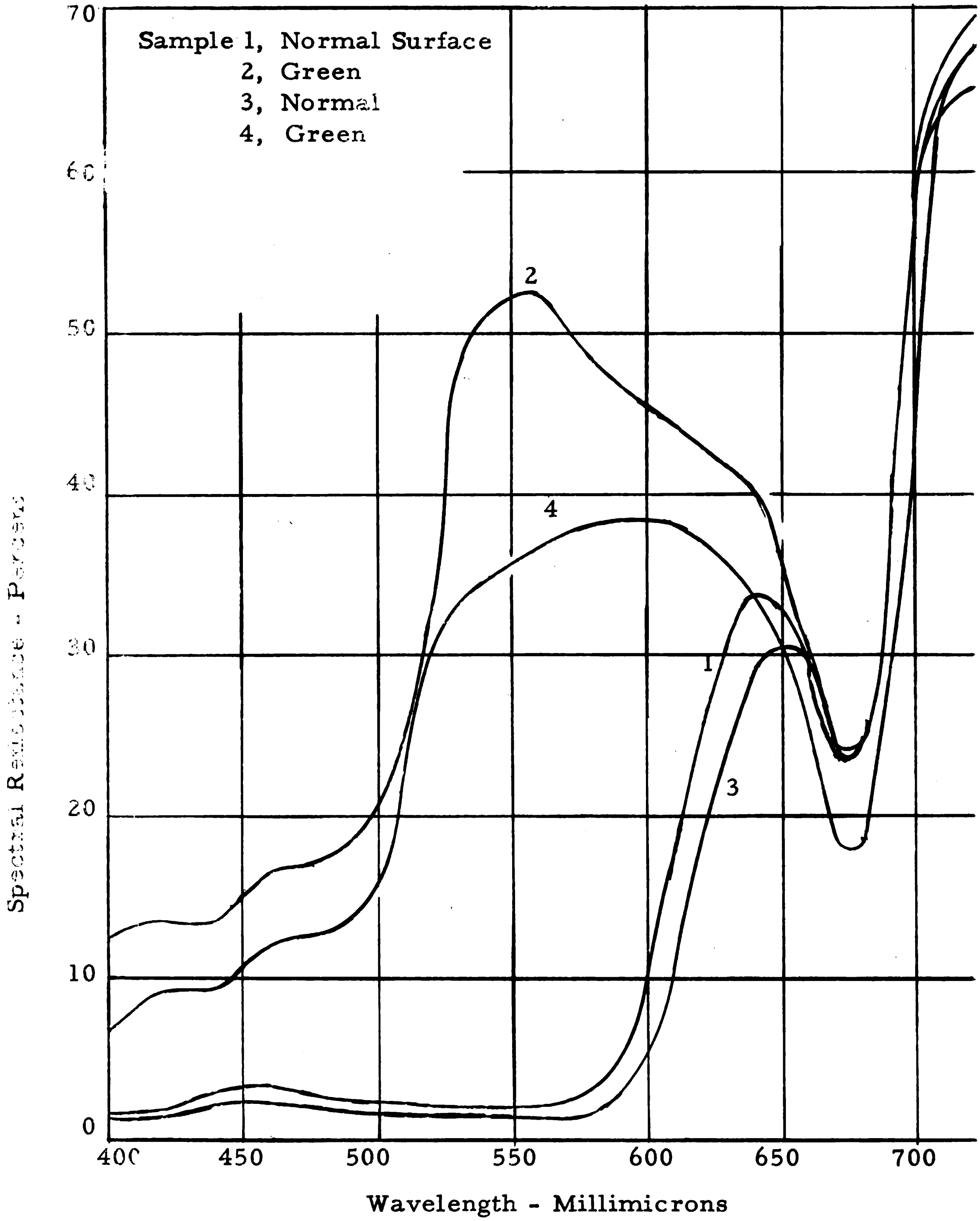


Figure 13. Spectral reflectance curves of the McIntosh apple samples. (Data from Table V)

APPENDIX II

APPLE PACKING PLANT SURVEY DATA

This section contains a copy of the survey form used to determine the present lighting systems in the apple plants. Also surveyed was the packing plant construction and color.

A summary of the numbered questions are found in Table X.

PACKING PLANT LIGHTING SURVEY

Name ________________________ Address _____________________

(1) Main apple varieties ______________________________________

____

(2) Other fruits packed in the plant ____________________________

(3) Packing plant size, _________ feet x ____________ feet.

(4) Construction, walls _____________ (5) color _____________

(6) ceiling _________ (7) color _____________

Type of electric service _____________ Entrance size _______ amp.

Lighting equipment

General illumination

(8) Type used, incandescent filament _____ fluorescent ___

(9) If fluorescent, tube color __________________________

(10) Is a reflector used _______ (11) Type ________________

(12) Mounting Height _____ Feet (13) spacing ____ x ___ ft.

(14) Lamp size _______ watts (15) Total no. ______________

Grader illumination

(16) Type used, incandescent filament _____ fluorescent ____

(17) If fluorescent, tube color ___________________________

(18) Is a reflector used _______ (19) Type _________________

(20) Mounting height _____ ft. (21) Spacing ______________

(22) Lamp size _______ watts (23) Total no. _____________

Grader

(24) Belt color __________________ (25) Composition _________

(26) Width __________ inch (26) Height _______ inch.

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Diagram of the packing room showing the location of the grading equipment, operators, location and types of the lighting equipment, including general illumination. (Note: show the ones used during the packing operation.) Include the location and size of all windows and doors. Show north..

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(28) Are there any shadows? __________ Cause? __________________

____

(29) Is there any glare? ______________ Cause ? ________________

____

What improvements, if any, would the owner suggest for the improvement of the lighting system? ___________________________

____

Interviewer ________________________

TABLE X

SUMMARY OF THE APPLE PACKING PLANT SURVEY

Packing Plant Number	Question Number 1	2	3	4	5
1.	Delicious Jonathan McIntosh Spy	None	30 x 50	Tile	Yellow
2.	do	None	20 x 60	Block	White
3.	do	None	30 x 120	Cinder Block	Silver
4.	do	None	30 x 100	Tile	Yellow
5.	do	None	30 x 150	Tile	Brown
6.	do	None	30 x 70	Tile	Yellow
7.	do	None	50 x 50	Cinder Block	Natural
8.	do	None	32 x 72	Cement Block	Green
9.	do	Peaches	38 x 45	Cinder Block	Gray
10.	do	None	40 x 100	Tile	Tan
11.	do	None	30 x 100	Cinder Block	Natural
12.	do	None	38 x 78	Cinder Block	Natural

TABLE X - Continued

Packing Plant Number	Question Number							
	6	7	8	9	10	11	12	13
1	Wood	Natural	I	x	Yes	RLM	11	15 x 15
2	Plywood	White	x	x	x	x	x	x
3	Wood	Natural	I	x	Yes	Shal. Dome	14	15 x 15
4	Steel	Galv.	I	x	Yes	Reces- ed	9	12 x 12
5	Steel	Galv.	I	x	Yes	Shal. Dome	14	10 x 15
6	Steel	Galv.	I	x	No	x	14	10 1 row
7	Building Board	Natural	I	x	Yes	RLM	15	20 x 20
8	Plaster Board	Natural	F	SCW	No	x	9	2 strips
9	Steel	Galv.	I	x	No	x	14	10 1 row
10	Wood	Natural	I	x	Yes	RLM	10	15 x 15
11	Wood	Natural	I	x	Yes	Shal. Dome	9	20 1 row
12	Wood	Natural	I	x	No	x	15	20 1 row

TABLE X - Continued

Packing Plant No.	Question Number 14	15	16	17*	18	19	20	21
1	200	5	F	CW	Yes	Indus-trial	6	8' on center
2	x	x	F	CW	No	x	10	7' on center
3	200	10	I	x	No	x	10	2.5 feet
4	100	11	I F	x SCW W	Yes No	Bulb x	7 7	1 used isolated
5	200	15	F	DL W	Yes No	Indus-trial x	7	isolated
6	100	5	I	x	Yes	Shallow Dome	7	3 to 7 ft.
7	200	5	F	CW W	Yes	Indus-trial	8	2 to 4 ft.
8	96	24	F	SCW	Yes	Indus-trial	8	isolated
9	100	5	I F	x SCW	x Yes	x Indus-trial	14 6	isolated one unit
10	150	6	I	x	Yes	Shallow Dome	9	variable
11	40 50	5	F	Spec	Yes	Indus-trial	7	isolated
12	150	3	I	x	Yes	Bulb	8	4 ft.

*Code:
CW Cool white; DL Daylight
SCW Standard cool white; Spec Special color
W White

TABLE X - Continued

Packing Plant Number	Question Number 22	23	24	25	26	27	28	29
1	96	4	Tan	Canvas, Rubber	24	36	No	No
2	96	6	White	Plastic	18	36	No	No
3	200	4	White	Canvas	24	36	Yes	No
4	150 96	1 4	Black	Rubber Canvas	18	36	Yes	No
5	40 20	2 4	White	Canvas	18	36	Yes	No
6	100	4	White	Canvas	24	36	No	No
7	40 96	10 2	Tan	Rubber	24	36	Yes	No
8	40 96	8 2	Natural Black	Chain Rubber	18	30	No	No
9	100 40	2 2	Black	Rubber	14	30	Yes	No
10	100	4	Black Natural	Canvas Chain	18	30	Yes	No
11	40 85	2 6	Green	Plastic	20	36	No	No
12	150	3	Black	Rubber	29	30	Yes	Yes

APPENDIX III

RELATIVE SPECTRAL DISTRIBUTION OF FLUORESCENT LAMPS

This section gives the relative spectral distribution of the common "white" Westinghouse fluorescent lamps. Other manufacturers make use of similar distribution data or curves. This data was taken from Westinghouse curves dated 1952 and 1953. From time to time the manufacturers change their specifications, thereby altering the data.

TABLE XI

RELATIVE ENERGY DISTRIBUTION OF SOME OF THE 40-WATT FLUORESCENT LAMPS

Wave-length Mu.	Percent of the Relative Energy Output*					
	Deluxe Cool White	Day light	Cool White	White	Warm White	Deluxe Warm White
400	15.5	29.0	14.0	9.0	5.0	4.0
10	20.0	39.0	19.0	11.0	7.0	5.0
20	24.0	52.0	25.0	15.0	8.0	6.0
30	29.0	60.0	29.0	17.0	9.0	7.8
40	32.0	66.0	34.0	19.0	10.0	9.4
50	36.5	70.0	37.0	21.0	11.0	10.6
60	41.5	72.0	40.0	22.0	12.0	12.0
70	45.0	73.0	42.0	23.0	12.0	13.0
80	47.0	72.0	43.0	23.0	12.0	13.5
90	47.0	71.0	42.0	23.0	12.0	13.8
500	45.0	68.0	42.0	23.0	12.0	14.2
10	44.0	64.0	41.0	23.0	12.0	16.0
20	46.0	61.0	42.0	25.0	15.0	21.0
30	53.0	61.0	44.0	29.0	22.0	24.5
40	65.0	66.0	54.0	39.0	34.0	41.5
50	76.0	76.0	66.0	56.0	50.0	58.0
60	85.0	86.0	81.0	74.0	76.0	71.5
70	92.0	97.0	95.0	90.0	93.0	84.0
80	97.0	100.0	100.0	100.0	100.0	91.5
90	100.0	93.0	94.0	95.0	94.0	98.0
600	97.0	84.0	86.0	83.0	85.0	100.0
10	92.0	73.0	74.0	70.0	70.0	98.0
20	85.0	58.0	59.0	56.0	57.0	91.5
30	75.0	46.0	47.0	44.0	54.0	82.0
40	64.0	35.0	36.0	32.0	33.0	71.0
50	53.0	27.0	27.0	24.0	24.0	58.0
60	42.0	19.5	20.0	17.0	18.0	48.0
70	29.0	15.0	15.0	13.0	13.0	38.0
80	19.0	11.0	11.0	9.0	9.0	27.0
90	12.0	8.0	8.0	7.0	7.0	18.0
700	9.0	5.0	7.0	6.0	5.0	12.5

*Data for this table taken from the spectral distribution curves prepared by Westinghouse Corporation.

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