



**MEDICAL RESEARCH COUNCIL
INDUSTRIAL HEALTH RESEARCH BOARD**

**THE EFFECTS OF CONDITIONS
OF ARTIFICIAL LIGHTING
ON THE PERFORMANCE OF
WORSTED WEAVERS**

By H. C. Weston

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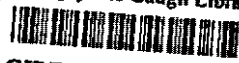
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1938

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PREFACE

The effects of conditions of lighting on the performance of industrial tasks has been observed incidentally in the course of a number of investigations made for the Board, and the results of these observations have been published in their series of reports. In 1926 there was published the first of a series of Joint Reports of the Industrial Health Research Board and the Illumination Research Committee of the Department of Scientific & Industrial Research. That report described the results of a particular investigation into the relation between illumination and performance in type-setting by hand.

The large part played by vision in the performance of almost every kind of work, and the obvious dependence of good vision on adequate illumination, points to lighting as one of the most important conditions of work within a factory. The experimental study of lighting under industrial conditions, however, presents difficulties no fewer than those which commonly attend similar studies of other environmental factors. The difficulties are chiefly those of finding or producing, in a factory, the controlled conditions of a laboratory experiment.

In the present investigation, which was made in a weaving shed where a night-shift was worked, one of these difficulties, namely the short and variable duration of artificial lighting during usual factory hours, was largely, although not entirely, overcome. The primary object was to test the value of a method of lighting looms which had been claimed to have given excellent results when tried in Germany. Confirmation of the German results has not been obtained, but the data presented suggest that a higher illumination than is customarily provided is necessary to secure the best performance in weaving certain kinds of cloth.

It must be admitted that, in view of the general variability in output recorded, far more data than it was found possible to obtain would be required to establish with certainty the conclusions arrived at. Nevertheless, both in respect of degree of illumination and method of lighting, the conclusions suggested by the present investigation and those drawn from the earlier type-setting experiments are mutually confirmatory. Though technically dissimilar, the work of the hand compositor and that of the worsted weaver largely consist of comparable visual tasks.

The Board therefore felt that the results of this investigation should be published, giving as they do some indication of what may be considered to be good lighting for a particular industrial process. In making this decision to publish, they have been supported by advice from the Committees on Vision and Statistics of the Medical Research Council and from the Illumination Research Committee of the Department of Scientific & Industrial Research. It seems to them, also, that the results gain particular current interest owing to the general clause in the new Factories Act requiring adequate and suitable lighting in factories.

THE EFFECTS OF CONDITIONS OF ARTIFICIAL
LIGHTING ON THE PERFORMANCE OF WORSTED
WEAVERS

By H. C. WESTON, M.J.Inst.E.

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APPENDIX I

A NOTE ON THE COMPARISON OF NIGHT WEAVERS' OUTPUT IN DIFFERENT EXPERIMENTAL LIGHTING PERIODS, AND ON THE COMPARISON OF NIGHT WITH CORRESPONDING DAY WEAVERS' OUTPUT IN THE SAME PERIODS.

In most field investigations it is exceedingly difficult to ensure that all the conditions within the factory which are capable of affecting the productive capacity of the worker shall remain constant, or nearly so, except the particular one the effect of varying which it is desired to study. This difficulty increases as the duration of the investigation is prolonged, for such conditions as those of temperature and natural lighting, for example, are subject to seasonal variation which cannot usually be confined within such narrow limits that its effect is negligible. In many cases also there are seasonal changes of product, particularly in certain textile factories.

Short period experiments, though permitting more rigid control of working conditions, are more likely to yield results which are influenced by "experimental effort," and it is known that the initial effects of changing some condition of work are not always maintained for long periods.

In the investigation described in the foregoing report the duration of each of the experimental lighting periods was usually five weeks and the investigation extended over a total period of ten months. It is obvious, therefore, that some conditions of artificial lighting had to be tried in summer and others in winter months, so that if a direct comparison is made between the results obtained in one lighting period and those in another any difference will not necessarily be wholly attributable to the difference of lighting but may be partly due to more, or less, comfortable conditions of warmth. It might be possible to estimate to what extent any such observed difference was due to the normal effect of seasonal changes, for example of temperature, by comparing the two periods under consideration with the corresponding periods of the previous year, or of several previous years, providing the nature of the work then done was strictly comparable. In the present case this procedure has not been possible.

Apart from seasonal changes, other conditions which affect the weaver vary from time to time to an extent which can be neither foreseen nor controlled, and it is not certain that the net effect of these variations will be the same in any two periods of five weeks' duration. For instance, a series of bad warps may occur in one period and not in another, and this will increase the difficulty of weaving though the kind of cloth woven remains the same.

In this investigation, however, the group of weavers selected for observation worked at night on looms which were also in operation during the day by a different group of weavers. It is thus possible to compare the output of the night weavers in any lighting period with that of the day weavers in the same period, both groups weaving the same cloth. Seasonal variations, and any variation such as in the difficulty of the work, will affect both groups of weavers and any difference between their respective performances, after allowing for any original group difference observed (which may be due to a difference of ability, or to a difference between the day and night loom speed due to variation of supply voltage), will then be at least mainly attributable to the change of lighting conditions imposed upon the night weavers.

However, if there is an improvement in daylight illumination this may raise the day weavers' output but will not affect that of the night weavers. Again, the day temperature may reach an uncomfortable level in summer and depress the day weavers' output, while the corresponding night temperature may have no unfavourable effect on the output of the night weavers. It is impossible to make any numerical corrections for the effect of such variations as these and they may, in some periods, depreciate the value of the day weavers' output as a standard of comparison. The extent to which any improvement of the night weavers' output is due to improved artificial lighting cannot, therefore, be exactly determined by this method though, on the whole, it probably gives a more reliable indication of the value of the lighting conditions

than does the comparison of the night weavers' output in the experimental lighting periods with their output under the original conditions of lighting.

Direct comparison can be made between the night and day weavers' performance in each lighting period if each performance is expressed as a percentage of the corresponding group performance achieved in the control period. The percentage gain, or loss, of performance by the night weavers will then be given by

$$\left(\frac{\text{night weavers' relative performance}}{\text{day weavers' relative performance}} - 1 \right) \times 100$$

APPENDIX II

THE SIGNIFICANCE OF OUTPUT CHANGES

WEAVING EFFICIENCY AND PERSONAL EFFICIENCY (SPEED OF HANDWORK)

In the process of weaving the output, i.e., amount of cloth produced, in any unit of time is proportional to the machine running time. The latter can never be 100 per cent. of the time unit because the looms must be stopped periodically to enable the weft in the shuttles to be replenished. There are, however, always other causes of lost machine running time, of which the most important is the breaking of "ends" (warp threads) which have to be "taken up" by the weaver while the loom is stopped. Accordingly, in practice, the weaving efficiency (ratio of cloth woven to cloth which would have been woven without loom stoppages, expressed as a percentage) may be only 75 or 80 per cent. In order to increase the output say by 1 per cent. either the number or duration of loom stoppages, or both, must be reduced. Assuming that the stoppages are limited in number to those which are unavoidable, so that the loss of output depends only upon their duration, this loss can be reduced only by an increase in the rate of working of the weaver. But, to raise the output in this way by 1 per cent. from 4,500 picks per hour (75 per cent. efficiency with a loom speed of 100 picks per minute) to 4,545 picks per hour (75.75 per cent. efficiency), means that the proportion of the total working time occupied in handwork by the weaver must be reduced from 25 per cent. to 24.25 per cent., and in this time he must do all the handwork he previously did in 25 per cent. of the total working time plus a little more made necessary by the additional cloth woven during the extra machine running time. His rate of working is, therefore, increased by

$$\left(\frac{75.75 \div 24.25}{75 \div 25} - 1 \right) \times 100 = \left(\frac{75.75 \times 25}{24.25 \times 75} - 1 \right) \times 100 = 4.12 \text{ per cent.}$$

It is thus evident that in power-loom weaving a relatively large increase of personal efficiency is necessary to effect a small increase of output, and the latter, considered by itself, gives an inadequate idea of the benefit derived by the weavers from any improvement of conditions to which it is attributable.

OPERATIONS IN WEAVING AFFECTED BY LIGHTING

It is mainly by making possible quicker perception of weft shortage—indicating the necessity for re-shuttling—and of warp breakages and the threads which have to be tied, and quicker discrimination of the heald eyes and reed dents through which broken "ends" may have to be drawn, that improved lighting can shorten the time occupied by the weaver in doing work requiring stoppage of the loom. Therefore, a very large reduction of handwork time cannot be expected, even with the best illumination, unless comparison is made with results obtained with extremely poor illumination. For example, a 12 per cent. increase of output, given an initial weaving efficiency of 75 per cent., would increase efficiency to 84 per cent., and would require the rate of handwork to be increased by 75 per cent. if the handwork required is proportional to the weaving efficiency. An improvement of this order would certainly be difficult to secure, as the result of improved visibility due to better lighting if the original lighting was good enough to permit an initial efficiency of 75 per cent.

PROBABLE EXTENT OF OUTPUT GAIN OBTAINABLE WITH IMPROVED LIGHTING

If the initial efficiency is low, say 50 per cent., a 12 per cent. increase of output requires an increase in the rate of handwork of 27.27 per cent., but, at the higher initial efficiency considered above, a 12 per cent. increase of output could probably only be secured by eliminating or reducing other causes of lost machine running time, such as breakdowns, absence of the weaver

while fetching weft, etc., but these are losses, some of which are either not reducible at all or are only reducible to a slight extent by better lighting.

When the loom is stopped the weaver has both to look at objects and manipulate them. Unless the lighting is very bad, more time is spent in doing something than in seeing what has to be done. When the loom is stopped for re-shuttling the time occupied in performing this operation mainly depends on the weaver's rate of action. The need for quick perception occurs *before* the loom is stopped, when the weft is running low and, of course, if the lighting is bad and the weaver cannot see properly, the weft may run out before the loom is stopped and leave an incomplete pick in the cloth to be removed before the loom is re-started. It is possible that several picks may be missed altogether in this way, and the warp will then have to be pulled back to restore the cloth fell to its proper position in which it abuts against the reed when the latter is at the forward end of its stroke. Time and output are lost in this way, but failure to stop the loom before the weft in a shuttle is exhausted can, and often does, occur because the weaver is occupied in attending to his second loom and cannot, therefore, keep the other one under constant observation at the same time. Thus loss of machine running time due to this cause cannot be eliminated by improvement of lighting and is likely to be reduced very little by increasing illumination beyond the moderate intensity which suffices to enable the weaver to see when the quantity of weft remaining in the shuttle is becoming small enough to necessitate re-shuttling. If the cloth is a fancy one, such as a patterned suiting, for which several shuttles are used, each containing weft of different colour, there may be so little difference between the colours that time may be lost in selecting the right one for insertion, and this, of course, can be diminished by improving illumination. The actual insertion of a new pirn of weft into the shuttle is usually done while the loom is running, a spare shuttle being available, so that any time saved in doing this, due to better lighting—and it will not be great as this operation is controlled much more by manipulative skill than by vision—will not as a rule affect output.

Thus, so far as re-shuttling is concerned, it is apparent that, unless performance in very bad conditions of lighting is compared with that in good or very good lighting, the difference of loom stoppage time, and therefore of output, will be small. The cloth woven during this investigation necessitated re-shuttling on an average about fifteen times per hour per loom, and each re-shuttling required stoppage of the loom for about fifteen seconds. If no incomplete picks had to be removed the total re-shuttling time per hour thus amounted to about $3\frac{1}{2}$ minutes. If, however, it is taken as four minutes, this is only 6.7 per cent. of the possible loom running time. Now, if better lighting increases the machine running time, and thus the output level, by reducing the time occupied in doing visual work when the loom is stopped, the increase of cloth woven would necessitate increased frequency of re-shuttling as well as of yarn breakage repair, so that the net time saved on re-shuttling under better lighting may be almost negligible. If, however, it is assumed that the net result of better lighting will be to reduce the hourly stoppage time by as much as 10 per cent. of the maximum re-shuttling time given above, i.e. by 0.4 minutes, and the initial weaving efficiency is 75 per cent. (the average weaving efficiency with the original lighting found in this investigation was 74.2 per cent.), then the loom running time will be increased to 45.4 minutes per hour, thus increasing the output by 0.89 per cent., and the overall rate of handwork by 2.74 per cent.

Apart from re-shuttling, the most important cause of lost machine running time which can be affected by lighting is the time required for piecing broken "ends." Here perception and discrimination play an important part in the work to be done, and more time may sometimes be spent in finding a broken end than in actually mending it, or in finding the appropriate heald-eye and reed-dent than in drawing a warp end through them. This, however, is by no means always the case, as a broken end may be easy to find or may be found partly by the sense of touch rather than sight. The actual operation

of piecing is quickly done, but, if several ends break at the same time, as often happens, the visual time element may be considerably increased in comparison with the manipulative time since care must be taken to piece the several threads in the correct sequence.

Obviously good lighting can reduce the time required for seeing in the process of piecing broken ends, but with the original lighting in the shed with which we are here concerned, it is doubtful whether the time occupied in seeing amounted to more than half the total time during which the looms were stopped for "taking up ends." An analysis of the stoppage times recorded during the first period of this investigation, with the original lighting, shows that, on the average, taking up ends occupied 30.32 per cent., or 3.335 minutes per hour, of the total stoppage time (excluding re-shuttling time) per loom. Assuming that 50 per cent. of this time is "seeing time" then, with a weaving efficiency of 75 per cent. $(15-4) \times 0.3032 \times 0.5 = 1.67$ minutes per hour is occupied by visual work in connection with the repair of yarn breakages. If this time can be halved, i.e., the speed of vision doubled,* by means of improved lighting the total stoppage time due to taking up ends will be reduced to $3.335 - \frac{1.67}{2} = 2.5$ minutes per hour.

But since any time saved in this way, and added to the loom running time, proportionally increases the number of yarn breakages requiring repair, the effective additional loom running time will be less than 0.835 minute. Taking it as 0.8 minute, the loom running time will be increased from the 45.4 minutes found above to 46.2 minutes per hour, thus increasing output, due to quicker re-shuttling and piecing, by 2.4 per cent.

In addition to stoppages recorded for the purpose of taking up ends, others were due to the weaver having to attend to his other loom. This means that while piecing ends, taking a piece of cloth off the loom, or doing other necessary work on one loom, the other has sometimes to be stopped to avoid faulty weaving. Thus the stoppage of one loom for any reason often involves lost running time for both. This cannot be avoided by improving lighting but, obviously, if the piecing time is reduced the stoppage time required for attending to the other loom will also be reduced, though not to the full extent of the piecing time saved, since the work done on the other loom does not consist only of piecing broken ends. It is difficult to estimate very accurately what proportion of the time lost on one loom while attention is given to the other is due to that attention being required for the purpose of taking up ends. Some of this stoppage time will occur while a piece is being taken off the other loom, as stated above, or while a picking-stick strap is being mended, etc., and it is very doubtful whether more than 25 per cent. of the time saved in piecing ends on one loom will also be saved on the other owing to the increased attention which the weaver is able to give it.

The percentage of the total hourly loom stoppage time, due to all causes except re-shuttling, which was recorded as due to "attending to the other loom" with the original lighting was 21.83. With a weaving efficiency of 75 per cent. this is equivalent to $(15-4) \times 0.2183 = 2.4$ minutes per loom per hour. As it has been assumed that 0.8 minute can be saved on piecing ends by means of better lighting, $\frac{0.8}{4} = 0.2$ minute will be saved on attending to the other loom, thus reducing this stoppage time to 2.2 minutes per loom per hour.

* With good contrast, having regard to the size of detail to be seen in worsted weaving, it would not be possible to double the speed of vision even by raising illumination to the high value of 500 foot-candles.† But if the contrast is poor and the material dark in colour, such a result may be possible—perhaps with a lower illumination.

† *Vide* "The Relation between Illumination and Industrial Efficiency. (1) The Effect of Size of Work." *Joint Report of the Industrial Health Research Board and the Illumination Research Committee.* H.M.S.O., London, 1935.

Taking the combined time saved on re-shuttling, piecing ends and attending to the other loom, i.e., $0.4 + 0.8 + 0.2 = 1.4$ minutes, the total stoppage time is reduced from 15 to 13.6 minutes per hour and the weaving efficiency is raised from 75 to 77.33 per cent. by a total increase of output of 3.11 per cent.

Time can be saved in connection with other operations, some of which are not performed by the weaver, but by the loom tender, but it is clear that the aggregate time which can be saved by improvement of lighting cannot be sufficient to produce a large increase of output if the initial efficiency is fairly high. Machine running time is lost, of course, from causes which cannot be influenced by lighting, such as the time lost when the weaver is away from the looms, and if this time can be reduced then a further improvement of output will be obtained. Much time may be wasted if the illumination is not sufficient to enable the weaver to detect a broken warp thread quickly, but this will be the time of the mender who has to sew in the missing portion of thread after the cloth is woven, and it will not, therefore, reduce the weaver's output.

So far, only the improvement of output likely to result from improved visual performance in connection with certain operations which normally account for more than half the total loom stoppage time has been considered. But manual performance may also improve with better lighting which induces feelings of well-being, contentment and alertness and thus tends to stimulate physical activity. This effect of lighting, primarily of a psychological nature, is due largely to the general appearance of the work-place. Investigation of this aspect of the problem of lighting, in the case of tile-pressers, has shown that when a local system of lighting, providing low illumination, badly distributed, so that the appearance of the work-place is gloomy and cheerless, is replaced by a general system, giving reasonable illumination, the rate of working is stimulated and output increased by about 6 to 10 per cent.*

The change of intensity of illumination was from an initial average value of about 1 foot-candle to some 4 to 5 foot-candles. The output of the tile-pressers was entirely controlled by their rate of handwork, but that of the weavers here considered was controlled by the rate of handwork only for about one-quarter of the total production time so that, even if the psychological effect of better lighting upon the weavers was of the same order of magnitude as in the case of the tile-pressers a net increase of output of only about 2 per cent. could be expected. Since, however, the initial illumination in the weaving shed was higher than that in the re-lighted tile-pressing shop, and the general appearance was reasonably good, an even smaller improvement of output due to the psychological effect of better lighting must be expected, especially as the general appearance of the shed was not greatly changed by the means employed to increase the illumination on the work.

Thus, from the foregoing discussion, it is evident that if a large increase of output is secured when the initial efficiency is high it will probably be due partly to the variation of factors other than lighting. In the present case, from the improvement of lighting alone, it may be expected that output can be increased perhaps by 5 per cent. but it is doubtful whether a much better result can be achieved.

* *Vide* "The Effect of Lighting on Efficiency in Rough Work (Tile Pressing)," *Joint Report of the Industrial Health Research Board and the Illumination Research Committee*. H.M.S.O., London. 1936.

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- BEDFORD, T. : "Requirements for satisfactory Ventilation and Heating". *Hum. Factor, Lond.*, 1936, 10, 245.
- "Warmth and Comfort." *J. Instn. Heat. and Vent. Engrs.*, 1936, 4, 383.
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- "Modern Principles of Ventilation and Heating." *H. K. Lewis & Co., Ltd., London*, 1937.
- CULPIN, MILLAIS : "Psychological Disorders in Industry." *Practitioner* 1936, 137, 324.
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- FARMER, E.: "The Human Factor in Accident Causation." *J. Insur. Inst. Lond.*, 1937, 29, 1.
- LANGDON, J. N.: "A Two-factor Study of Simple Motor Tests with Particular Reference to Practice and Prognosis." *Brit. J. Psychol.*, 1937, 27, 4.
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