

Discussion.

Mr. S. B. DONKIN remarked that it was of great advantage that Mr. Donkin. The Institution was able to discuss such a Paper with the impartiality arising from the fact that it represented all branches of engineering, and held no brief either for the electrical engineer or for the gas engineer.

The Author, in his list of the disadvantages of electricity, referred to the possibility of the generating-station breaking down and causing much greater dislocation than would occur in the case of a failure of the gasworks. That statement, in the main, was true, apart from the fact that the Author appeared to have overlooked the advantages of the Central Electricity Board's connecting lines between selected generating-stations; those lines provided a second source of supply to the generating-stations concerned. That fact should not be overlooked, although it assumed that no two break-downs would take place at the same time.

The Author had referred to a two-part tariff, with both fixed and running charges, as being applicable in the case of electricity because electricity could not be efficiently stored in bulk. Gas, on the other hand, could be, and was, stored efficiently and economically, and he therefore wondered why one of the London gas companies had recently introduced a two-part tariff. Having regard, however, to the Author's figures for the cost of distribution, he realized that a gas undertaking might wish to save expense by restricting the capacity of its gas-mains. If that could be confirmed by the gas industry it would be a valuable additional contribution.

It would be of advantage if the Author would add a bibliography to his Paper, so that it would be possible to look up some of the references from which he had taken his facts.

Professor W. A. BONE explained that he had not yet had the Professor Bone. opportunity of studying the Paper sufficiently in detail to offer criticisms in regard to some of the Author's statements; his general impression was that it contained many statistical arguments and deductions, some of which he would be inclined to question. He had, however, studied one or two of the cases cited in Table XVII, and he did not disagree with the conclusions reached therein. He might, therefore, appear to be in more general agreement with the Author than would be the case if he had had time to make a detailed criticism of the Paper.

Professor Bone. There was one general point which he desired to make before putting some questions to the Author. Gas and electricity were two forms of energy, both of which in this country were ultimately derived from coal. Gas was a form of energy which was derived by carbonizing the coal at an efficiency of about 80 per cent. when account was taken of all the products; and although not at high potential, when mixed with air it could be burned to produce a temperature of up to about 3,600° F. Heat could be produced very cheaply in that way, but not energy at high potential. Electricity, on the other hand, was a form of energy which was at a very much higher potential than gas, but it was produced with an efficiency at the generating-station of about 25 per cent. at the most. If the two kinds of generation were compared it was found that the energy in the electric current generated from a given amount of coal consumed in a power-station was about equal to the energy in the gas produced in a gas-retort from the same amount of coal, while all the available coke after firing the retorts, as well as the tar by-products, had to be credited to the carbonizing process.

If there were a unified authority, having full control of both gas-works and electric power-stations, for supplying energy to the inhabitants of Greater London, he thought that it was true to state that the whole of the heat-energy requirements could be generated and supplied in the form of gas more cheaply than in the form of electricity. In that case, however, electricity would be generated only for the highest potential requirements, and a proper load-factor could not be obtained for the generating-station. It would therefore become a question of what proportion of the heating requirements of the area ought to be allowed to electricity, in order to secure a good load-factor for the power-station.

He wondered whence the Author had obtained the figures of capital costs shown in Table I of the Paper. About a week before he received the Paper he had been studying the last Report of the Electricity Commissioners, and he found that, taking all the authorized generating undertakings in Great Britain, for the year ending 31st March, 1933 (the last for which figures were given), the fuel-costs per unit were given as 0.137*d.*, and all other costs as 0.077*d.*, which, excluding capital charges, came to 0.214*d.*; this was not very different from the Author's figure of 0.22*d.* It was not quite clear what the Author meant by the net cost of coal, because the average figure in the Report of the Commissioners was 0.137*d.* The Author, however, gave a figure of 0.103*d.* for "Interest and depreciation on capital, etc.," and then gave a figure of 0.323*d.* as "Gross cost at works." The Commissioners, on the other hand, gave the total amount of capital expended in these undertakings,

and they said that roughly one-third was for generation and two-thirds for distribution. Taking 10 per cent. on the one-third of the capital applicable to generation, he arrived at a figure of 0.281*d.* If the cost at the generating station, including interest and depreciation on capital, were taken as 0.6*d.* per unit, and 7½ per cent. were added to that figure in respect of the capital applicable to distribution the total cost per unit would be 1.28*d.* Another point which was not referred to in the Paper was that the average loss in the distribution of electricity was about 18 per cent., as, according to the Commissioners' figures, only 82 per cent. of the current sent out of the station reached the consumer.

He had dealt with the question of capital charges¹ in a recent article. In that article he stated that, if interest charges were taken on a 5-per-cent. basis in respect of the heat-energy supplied to the public by both gas and electricity undertakings, it would be seen how very favourable they were to gas. On such a basis the average interest-charge per ton of coal carbonized at British gas undertakings was 116*d.*, and as the potential therms sent out from it were 150 as coke and 75 as gas, or a total of 225, the interest-charge would be practically ½*d.* per therm if spread over the whole of the heat-production or, if charged on the gas alone, 1½*d.* per therm. On the same basis, the average interest-charge per ton of coal consumed in British electricity undertakings was 348*d.*, and, as the potential heat in the current generated from that ton was equivalent to 75 therms, this meant an equivalent interest-charge of 4.64*d.* per therm. Therefore the interest charges on capital, taking the interest at 5 per cent. (and with any other rate of interest the proportion would be the same) would be three times as much for electricity as for gas, even if all the interest were charged against the gas and none against the coke and by-products.

Having studied the question for many years, he believed that, from the point of view of the use of the coal-resources of Great Britain, most of the energy to be distributed for heating-purposes should be generated as gas. Were it not for the necessity of obtaining a satisfactory load-factor for electric power-stations, which was all-important as electricity could not be stored, there would, in his opinion, be no justification for the use of electricity for heating-purposes in the great majority of cases. He did not think there was much justification, except on the question of load-factor, for burning coal at a power-station, generating electricity, and then reconverting it into heat.

¹ "Gas or Electricity for Domestic Heating?," *Nineteenth Century and After*, vol. cxvii. (1935), p. 712.

Dr. Fishenden. Dr. MARGARET FISHENDEN said that she did not find the Paper very provocative, because it consisted so largely of plain statements of fact. The Author, however, seemed to set out to make a general comparison between gas and electricity, and very soon found that the conditions were so complicated that the two agents could not be compared in any general way. It was not possible to state in a few words or in any general expression how much cheaper or dearer gas was than electricity. That did not mean, however, that it was not possible to get very good comparisons in particular cases; and the information which the Author had gone to so much trouble to give in his Paper would be helpful in making those comparisons for particular cases.

She thought that a simple way of looking at the matter was from the point of view of initial coal-consumption. The efficiency of generation of electricity from coal might be taken as 20 per cent., and the efficiency of production of gas from solid fuel as 50 per cent., because from 100 therms in coal approximately 25 therms in gas and 50 therms in coke were obtained, and, if it were assumed that the coke was equivalent to coal of corresponding thermal value, then 25 therms of gas had been produced from the 50 therms in solid fuel, which was an efficiency of 50 per cent. Hence, for the same initial coal-consumption electricity had to be five times as effective as coal and gas twice as effective; or, comparing gas and electricity, electricity had to be two-and-a-half times as effective as gas.

If the comparative costs were considered, there was a still greater discrepancy in cost between coal on the one hand and gas or electricity on the other, because of the additional costs of production and distribution. Taking average prices, such as coal at 45s. per ton, gas at 9d. per therm, and electricity at 1d. per unit, heat in gas cost about five times as much as in coal, and heat in electricity about fifteen times as much, so that in order to cost the same to the consumer gas had to be about five times as effective as coal and electricity about fifteen times as effective.

Those figures showed what a long way electricity had to go to be able to compete with coal, or even with gas. At $\frac{1}{3}$ d. per unit electricity cost the same as gas, and, as was well known and as the Paper proved, in some cases a higher price could be counter-balanced or even over-balanced by the increased efficiency possible with electrical apparatus. For heating-purposes the portability of electrical appliances was probably their greatest advantage.

The only other point on which she desired to touch was the question of the distribution of heat, to which the Author referred on p. 254. There was, however, an aspect of that question which

she thought had not received sufficient prominence. The Author Dr. Fishenden, pointed out that many heating appliances did not give a uniform distribution of warmth over a room. There was, however, another very important point to be taken into account, namely, the distribution of the heat over the human body. It did not follow that, because two appliances gave the same total amount of heat, or even because they gave the same proportions of radiation and air-heating, that they would be equally comfortable. If a high-temperature heater of very small area was used when the weather was cold, it was necessary to go so near to the heater that only a small part of the body was warmed, and that part was heated too intensely. That led her to question whether intermittent heating by the usual type of gas or electric appliance could ever be really comfortable in cold weather, and she would suggest to designers of electric heaters and gas fires that alterations might be made in the size and shape of the appliances. In cold weather an intermittently-heated room would have very cold walls, and it was not possible to produce comfortable conditions by the local application of intense heat.

There were two reasons why the open coal fire was so comfortable. One was the gradual heating-up of the room, furniture, carpets and walls, which meant that a smaller intensity of radiation sufficed for comfort; the other was the gradual heating-up of a large area surrounding the fire itself, which meant that the distribution of the radiation over the actual body was more uniform.

Mr. ROGER T. SMITH remarked that it was impossible to take due Mr. Smith account of all the items that should be considered for the solution of any one of the problems which the Author attacked. Many of those items were psychological, and one of the merits of his lucid Paper was that the Author stressed the fact that there were so many unknown factors, and gave constant warnings against using the facts given in the Paper without intelligence.

In comparing gas and electricity for the space-heating of buildings, the Author very properly insisted on the importance of ventilation. It had been entirely neglected in many modern flats and offices which were heated electrically; the openings to existing chimneys had been closed, and chimneys had been excluded from the designs of modern buildings. Certain electrical engineers had even gone so far as to boast of having saved the cost of chimneys and flues in buildings that they had equipped. Fresh air was, however, just as important for comfort and for health as warmth, and, even if there were no fire in a grate, a chimney was one of the best ventilators that a room could have, and, when the fire was alight, a small vent high up near the ceiling with a mica flap-valve opening into the

Mr. Smith. chimney-flue was very useful. He ventured to suggest that the 50 per cent. loss of heat up the chimney from a gas fire should not be counted against it, as that effect was in fact one of its greatest advantages over electric heating. The Author almost claimed that under the heading of "Local Heating," but was so judicious that he did not press the point. He would like to ask the Author whether it was quite correct, under the heading of "Ventilation," to speak of heat propagated by radiation being taken up the chimney. Radiation heated the objects in a room much more than it heated the air, which was warmed principally by convection, and it did not seem correct to say that the heat propagated as radiation was subsequently removed by warm air going up the chimney.

There was an incidental heating-effect arising from the use of flues and chimneys, which the Author did not appear to have taken into account. If several flues passed through a partition-wall, when the fires were alight the effect was that of an almost ideal form of panel-heating. The only objection to it was that the heat could not be regulated; otherwise it was a fortunate and most pleasant addition to the general heating of a house.

His own conclusions, from his experience and from the present Paper, were that ideally no one form of heating was sufficient; for warmth combined with ventilation a fire of some sort with a flue was required, and portable electric radiators of small power, 750 or 1,000 watts, were a very useful addition. If hot-water or steam heating were also available, a combination of all three methods, or at least of two of them, could provide almost perfect space-heating of buildings.

Mr. Lacey. Mr. STEPHEN LACEY said that he had had the pleasure of knowing the Author for a number of years, and, as his own work was connected with the distribution and utilization of gas, he was familiar with the subject-matter of the present Paper and also with the Author's earlier publications, which covered very much the same ground. The rivalry between the gas and electricity supply-companies had applied a stimulus which had been largely responsible for the great advances made during recent years in the design and efficiency of both gas and electrical appliances and also in the service to the public. The Author had suggested that advantages might accrue if the two industries were amalgamated. That was a very interesting point, but it was not suitable for discussion at a technical meeting.

From a technical point of view, the Paper contained so many figures and statements which called for comment or correction, and perhaps for discussion between specialists, that it was hardly possible

to do more than draw attention to certain points which seemed to Mr. Lacey, be outstanding.

The Author appeared to attach too much importance to the comparative dangers of gas and electricity, and quoted the number of suicides due to gas-poisoning (Table II). In the same Table the Author gave the accidental deaths due to gas and electricity; the Author quoted those figures without comparing them with the total number of accidental deaths, which was 15,829 for the year 1934. Again, after reading the Paper it would hardly be imagined that, if reference were made to the Registrar General's record, it would be found that nine times as many people met their death by accidentally falling downstairs, or elsewhere in their houses, as by accident due to either gas or electricity. In fact, the use of either gas or electricity was remarkably safe, and such accidents as did occur were generally due to badly-designed or improperly-installed appliances, which both industries were doing their best to eliminate.

Mr. Lacey wished to make the most emphatic protest against the Author's statement that the use of gas "gives rise, along with the heat, to the emission of products of combustion which are mainly of a deleterious character." As a general statement, that was quite untrue. The products of combustion of gas were almost entirely carbon dioxide and water-vapour, and the great majority of gas appliances were to-day, and always had been, used without a flue and without any ill-effect to the occupiers of the room in which they were fitted. There were millions of people to-day who used gas for lighting and heating their homes, and the suggestion, made without producing any supporting evidence, that there was something deleterious in the products of combustion was quite unjustifiable.

He agreed with the statement made in the Paper that the hygienic condition of a room was greatly improved by adequate ventilation; in that connection he had listened with great interest to the remarks of Mr. Roger Smith. The provision of chimneys was in general practice the most satisfactory way of ensuring the adequate ventilation of living-rooms, and there could be no doubt that the modern tendency to build flueless rooms was retrograde, and was a false economy. An air-vent was not a proper substitute for a flue.

He did not propose to comment on the question of the relative efficiencies of gas and electricity, as he hoped that Mr. C. A. Masterman would deal with that subject. Mr. Lacey could not understand the details of the capital costs of production and distribution on pp. 218 and 219 of the Paper, to which Professor Bone had already referred. The Author stated that ". . . a gas-main generally costs from three

Mr. Lacey. to five times as much as a corresponding buried electric cable, and from ten to twelve times as much as electric cables suspended overhead," and concluded from this that the capital charge on distribution was very much higher with gas than with electricity; Mr. Lacey, however, believed the reverse to be true. In the case of his own company the capital charge on distribution for the gas sold was well under 1*d.* per therm, whereas he thought that the average capital charge per unit of electricity sold was in the neighbourhood of $\frac{1}{2}$ *d.* It might be that that included other things besides capital charge, but, even if it were only $\frac{1}{4}$ *d.*, that was equivalent to $7\frac{1}{4}$ *d.* per therm. It would therefore be of interest to know how the Author arrived at his conclusion.

With regard to the cost of production, the Author gave 6*d.* per therm as the gross cost of gas at the works, and 0.323*d.* per unit as the corresponding cost of electricity. It would seem, however, that that comparison could not be correct, because the average price of gas to the public was only about 9*d.* per therm, and in some parts of the country it was less than 6*d.*; that was to say, it was sold at less than the figure given by the Author for the cost at the works.

He could understand the Author's difficulty in giving significant figures of cost of production and distribution, because they were so greatly affected by the load-factor and by overhead charges. That fact was generally recognized with regard to the supply of electricity, but it also applied to the cost of supplying gas, although to a rather less extent. That was why some gas undertakings had adopted block rates or two-part tariffs. One speaker had suggested that the only reason for a two-part tariff in charging for electricity was the fact that electricity could not be stored, but that was certainly not the case; the best-known two-part tariff was that of the Post Office, where the question of storage did not arise. The question was more one of the relation between overhead costs and the extent of the use made of the service. Such tariffs appeared to be quite equitable and economical, both for the supply-undertakings and for the public, provided that the disparity between the flat rate and the lowest charges did not become unreasonably large.

In conclusion, he did not wish to appear ungrateful to the Author for the great trouble which the preparation of the Paper must have involved. It was necessary to remember, however, that the acceptance of a Paper by The Institution, to which both he and the Author belonged, gave it a currency and invested it with an air of authority which might or might not be justified. That was especially important when, as in the present Paper, technical and commercial considerations were so closely associated.

Mr. E. R. DOLBY remarked that the heating of buildings had not Mr. Dolby. in the past received very much attention from The Institution. Considering, however, the monumental building over St. James's Park station, as well as the many other large and important all-electric buildings in Great Britain, it seemed clear that in the future the subject would prove of increasing importance to its members. He had therefore read with great pleasure the interesting Paper under discussion.

In the section of the Paper dealing with the thermo-dynamic use of electrical power, the Author foreshadowed a possible efficiency of 500 per cent. Mr. Dolby felt that the Author must be a member of the Magicians' Circle! It would be of the greatest general interest if the Author in his reply would elucidate his statement that, apart from its capital cost, the method was a conceivable future development for the warming of buildings.

He would like to refer to a previous Paper by the present Author which dealt with the heating of the large premises of a firm of drapers.¹ The heating was effected by means of air warmed by electricity and delivered into the building by fans housed on the roof. He would like to inquire whether that installation had continued to give satisfaction, both from the technical and from the financial aspect.

Finally, he would like to allude to *Fig. 4*, in which the consumption of hot water for domestic purposes was dealt with graphically. The results were stated to have been collected from sixty houses in three different districts, and therefore seemed to deserve the most careful consideration.

Mr. J. I. BERNARD expressed his appreciation of the Paper, which Mr. Bernard. covered a wide field of specialized applications. In reviewing the Paper and the methods of comparison adopted in it, it might be said that the Author had in some places fallen into the familiar trap presented by an academic comparison of heating-costs based on the potential heating-values of gas and electricity, as distinct from practical working-figures. He had, however, given, as a final comparison under each heading, the practical equivalent costs. Mr. Bernard suggested that it was a little unfortunate from that point of view that Table XVII, which might be read, and indeed had been read that evening, as a final summary of the Author's conclusions, should not give those practical equivalents. With regard to cooking, for example, the conclusion in the text was clearly

¹ "The Electrical Heating and Ventilation of Bourne and Hollingsworth's Premises, Oxford Street." Minutes of Proceedings Inst. C.E., vol. 228 (1929), p. 1.

Mr. Bernard. reached that electricity at 0.7*d.* per unit was equivalent to gas at 10*d.* per therm, but in Table XVII various figures were given, ranging from 0.51*d.* to 0.60*d.* per unit of electricity as the equivalent of gas at 10*d.* per therm.

The Author had implied that the thermal efficiency of gas-making was about 80 per cent., but that was only true if full value could be obtained from the coke and other by-products. The efficiency of gas-making *per se* was no higher than the thermal efficiency obtained in the generation of electricity. Further, the coal used by the gas industry was greatly superior to that used by the electrical industry, and the use of the higher-grade coal would tend to exhaust the coal-resources of Great Britain more than the use of the inferior coal used in electrical power-stations. If, however, the problem of coal-conservation was one requiring serious analysis, he thought it should be done in terms of the useful service obtained. For example, the coal used for producing gas for lighting was probably five times as much as that used in generating electricity for electric lamps of equal candle-power to the gas burners.

Of the principal advantages of gas, as summarized on p. 223, the second and third should be qualified by a statement of the fact that a sudden increase in the use of gas would produce a drop in pressure, which in turn would upset any exact regulation. The statistics of fatal accidents given in Table II were also misleading unless it was borne in mind that 75 per cent. of the electrical fatalities took place in factories and similar places, in which gas was not used to any extent. If that allowance were made, it would be seen that electricity was much safer than gas in domestic use, as well as for other purposes.

He was glad to see that the Author had assessed the reliability of electric service more fairly than was sometimes the case. The use of electricity was so popular that the slightest failure of supply became a news-item in the press, whereas statistics showed that the number of interruptions, when expressed in consumer-hours, was an insignificant percentage of the total service given, and was, in Great Britain, a much lower proportion than in other parts of the world. In dealing with the principles of comparison it was satisfactory to find that the Author, although he had had a much closer connection with the gas industry than with the electrical industry, was prepared to give some credit for the advantages in use which electricity generally had over gas. One of the difficulties which faced the electrical industry was, however, the fact that electricity was nearly always the "second comer," and consequently people did not have so much chance of appreciating the practical value of electrical methods.

In the section of the Paper dealing with lighting, he suggested Mr. Bernard. that the Author might have taken some more up-to-date figures. Independent tests of some of the latest types of gas burner had shown consumptions in the neighbourhood of 48 B.Th.U. per spherical candlepower-hour, and the British Standard rating for the smaller-sized electric lamps of 60 watts was $12\frac{1}{2}$ lumens per watt. From those results the figures for gas burners in Table V appeared to be optimistic, and the figures for electric lights pessimistic. Further, with regard to Table IV, the sodium lamp was stated to give 20 lumens per watt; lamps of that type giving 70 lumens per watt had, however, been in commercial production for some time, and experimental lamps had been produced which gave a much greater efficiency than that figure. In regard to street lighting it might be said that the Author's personal preference for gas as a means of illumination hardly corresponded with the great progress which was being made by electric lighting in displacing gas. For example, no less than 330 miles of streets were included in eight conversion schemes which had recently been adopted.

The Author was to be congratulated on the very full analysis of the comparisons for room-warming and water-heating. Although those analyses were probably carried further than anything that had been published before, it was doubtful whether even they reflected all the savings which were possible by means of electricity, as they generally indicated a comparison of about 15 units as being equal to 1 therm of gas, whereas practical experience showed that, if electricity were properly utilized, 10 units might be equivalent to 1 therm.

In connection with furnace-work, the use of gas for industrial heating was discussed briefly in the Paper, and the Author recognized the loss of efficiency which occurred in gas firing when high temperatures were required; but the temperatures which the Author took in Table XVII were not applicable to ordinary furnace-work such as carbonizing and hardening, which required temperatures in the neighbourhood of $1,700^{\circ}$ F. For those purposes the relative economy of electricity was evidently much higher than that stated by the Author.

The Paper was mainly concerned with comparisons between units of electricity and therms of gas, but the relative cost was clearly the final criterion for the consumer. The Author made but slight reference to that aspect of the problem, and he was apparently not fully aware of the extent to which the cost of electricity had been reduced in recent years. For example, the price of electricity for domestic purposes had been reduced by more than 50 per cent. in

Mr. Bernard. the last 10 years, and to-day 80 per cent. of the public could purchase electricity for heating and cooking at $\frac{3}{4}d.$ a unit or less, at which price, as the Author showed, electricity was as cheap as gas at 10d. per therm.

Lord Pentland. Lord PENTLAND desired to draw attention to one general feature of the Paper which had not yet been mentioned, namely, that the comparison was of necessity made as at the present date, and took no account of the trend in relative costs of the two agents. In estimating running costs for any particular installation an engineer would be bound to take into account any probable future increases or reductions in the tariffs for the two services. For example, the supply of electricity was of much more recent development than that of gas, and substantial progress had been made in the past few years in improving the efficiency of generation, distribution and application. Assuming that that progress might be expected to continue in the next few years, the whole comparison would be modified in favour of electricity. An outstanding example of such a modification would arise if the heat-pump cycle were to be adopted generally as a heating process. Further, any substantial increase in the cost of coal might be expected to cause a larger increase in the cost of gas than in that of electricity, particularly if the demand for gas-residuals were fairly elastic. A reduction in the cost of coal would have the opposite effect. The Author made no reference to diversity and load-factor as affecting the costs of gas and electricity. Broadly, it was true to say that both agents became cheaper as consumption increased, but that effect was greater in the case of electricity than of gas; firstly, because in the case of electricity the capital investment was greater, so that the overhead charge to be spread over the units was greater; and, secondly, because electricity could not be stored, so that diversity was of more importance than in the case of gas. For the above reasons, it would be fair to say that in a case where there was little to choose between the estimated present running cost of electricity or gas, electrical methods would be likely to prove more economical over an extended period.

He would also like to express his appreciation of the admirable way in which the Author had summed up the position in the "General Conclusions."

Mr. Grierson. Mr. RONALD GRIERSON remarked that, in spite of the Author's long connection with the heating industry, especially notable for his invention of the invisible panel warning system, he seemed still to be in a state of philosophic doubt with regard to the relative merits of the various heating agents. It was to be hoped that the discussion, that evening would enable the Author to make a final decision on the

subject, so that he might be determined in future to specify electricity *Mr. Grierson*. as the agent to be employed.

The Author had made somewhat disparaging reference to the low thermal efficiency of electric generation, quoting values of the order of 20 to 25 per cent., but Barking and several base-load stations were now operating at efficiencies of $28\frac{1}{2}$ per cent., and even better figures would undoubtedly be obtained in the near future. It was useless to talk about efficiency at the consumer's terminals. In Barnet gas was being advertised not by the therm but by the "gas unit" of 4,000 B.Th.U., and that was compared with the 3,400 B.Th.U. of the kilowatt-hour. The comparison was misleading, because the potential consumer was not told that he would get only 50 to 70 per cent. of the 4,000 B.Th.U., instead of the 100 per cent. of the 3,400 B.Th.U. which he would get from the kilowatt-hour. Again, the relative cost of the coal used by the two industries should be mentioned, together with the over-all efficiency value between the raw material and the utilization of the agent, because the relative efficiency at the purchase stage was purely an intermediate figure.

With regard to the cost of installation, one authority in London piped a block of eighty-four flats free for gas, but the wiring was paid for at standard rates. Even so, seventy-eight tenants chose to utilize electricity for all purposes, and only six used gas for cooking and heating at the outset, none using gas for lighting. It would therefore appear that in the opinion of the tenants the advantages of electricity completely outweighed all other considerations.

He entirely agreed with the Author's remarks on the appearance of gasholders. Some friends of his had built a house near Richmond; after they had spent a substantial sum on the property, the gas company found it necessary to erect a Falstaffian gas "substation" within 100 yards of the property, with disastrous effects on its value. His friends were so annoyed that they now used electricity.

The Author appeared to confuse the process of storage on site with that of storage at the gasworks, regardless of the pressure-drop in the mains and distributing pipework. Surely he did not mean to infer that the present capacity of gas-mains was absolutely unlimited? A point of saturation of the existing network due to pressure-drop was bound to arise; and gas would then either have to be supplied on an off-peak and peak basis very much as in the case of electricity, or the pressure would have to be raised and governors or reducing-valves provided either for every installation, or for the control of districts.

The Author made several references to flueless gas heaters, which discharged the products of combustion into the occupied room.

Mr. Grierson. Was it to be understood that he really recommended such heaters as being hygienic, particularly as he mentioned that they would inevitably cause excessive humidity?

The most important point which he wished to stress was that of national safety, particularly as it had now been found necessary to repair the gaps in British defences. He spoke with the experience of one who had been responsible for the maintenance of electrical and mechanical services behind the lines in France during the latter part of the War. He had found that the miniature electricity-supply "grid," which was intended to stretch ultimately from Dunkirk through to Bethune and Arras, was practically immune from damage or destruction by bombing. One span had been brought down by an intense bombing attack, but it had been restored in about three-quarters of an hour; yet that was during the intense bombing of the back areas in early 1918. He felt, therefore, that the Central Electricity Board had rendered an invaluable service to the defence of the country by inter-connecting all the power-stations, so that if by bad luck any of them were bombed the supply could be maintained. It could not be overlooked that gas lighting of railway rolling stock was being eliminated, because accidents in the past had often been followed by fire due to ignition of the gas. The devastation wrought by the gas explosions in the old Post Office tube in December, 1928, might also be mentioned; it indicated the nature of the damage which might be done if London were bombed. At the time when the Post Office tube blew up the gas-mains could only be cut off by digging holes in the road, drilling holes in the pipes, inserting bladders in the pipes, and inflating them. Had the gas undertakings developed any better methods of control? If another war broke out it would be a very different affair from the last one, and he felt that the risk of escaping gas being ignited by incendiary bombs could not be overlooked. In the event of an air-raid alarm, what would happen if the gas supply of a large town were shut off in order to ensure a 100 per cent. black-out, and then restored at short notice?

With regard to accidents, he thought the proper criterion was not the number of installations but the number of people daily associated with the innumerable uses of electricity. He ventured to submit that the users, as distinct from the registered consumers, of electricity vastly outnumbered the users of gas, and, viewed in that way, the statistics quoted by the Author would assume an entirely different aspect.

The Author stated that the observed cost was always a function of the efficiency, but it might be asked whether a Savile Row suit was essentially inefficient compared with the products of a fifty-

shilling tailor. There was a very extensive market for the more costly products because they were more effective. Mr. Grierson.

Like the Author, he had been attracted by the possibilities of the heat-pump, and he had studied the system very closely in connection with a town-hall building in London, for use in conjunction with an invisible ceiling panel-warming system and an air-conditioning plant, the heat being "pumped" from the atmosphere. Although a heat-pump plant absorbing 400 kilowatts would do the work of a 1,000-kilowatt electrode boiler, and would therefore show an apparent efficiency of 250 per cent., the scheme proved to be impracticable at the present time. Instead of the relatively simple and straightforward electrode-boiler and its control-gear, the heat-pump plant would include ammonia-compressors absorbing about 240 B.H.P., a 20-B.H.P. fan designed for a duty of 70,000 cubic feet per minute, and an air-cooler containing some $4\frac{1}{2}$ miles of pipes, which would possibly have to be duplicated to allow for de-frosting periods. The temperatures at which the plant would operate precluded the possibilities of thermal storage, so that a peak-load charge of £5 per kilowatt for 400 kilowatts, or £2,000, was involved, plus the metered charge for all units metered. During the off-peak periods 2,000,000 units could be purchased for the amount of the fixed charge alone; labour-charges still remained to be added, and duplication of plant seemed essential to guarantee continuity of service, so that the scheme was dropped. Those who were familiar both with refrigerating-plant and electrode-boiler plant would not hesitate for a moment to say which scheme was the simpler and more likely to give satisfaction, although there were distinct possibilities for a combined swimming-pool and ice-rink plant, which would be used for freezing in winter and for warming the water in summer.

With regard to gas lighting, the Author did not appear to have stated the cost of the motor-driven fume- and heat-extractors which were considered by the managers of gas showrooms to be essential for the well-being of the decorations and of their customers and staff. Again, it was the effectiveness of electricity that dominated the position, and it was the smell, risk of explosion, poisoning, excessive humidity, increased maintenance-cost and risk of derangement which were such severe handicaps to gas undertakings in the sale of their products.

He could not accept the Author's figures for the effectiveness of the lagging of electric water-heaters; in his opinion the heat-losses given were at least 35 per cent. too high. With regard to daily efficiency, in a paper¹ read before the Institution of Electrical

¹ R. Grierson and D. Betts: "The Electrical Warming of, and the Supply of Hot Water and Conditioned Air to Large Buildings," *Journal Inst. E.E.*, vol. 76 (1935), p. 461.

Mr. Grierson. Engineers Mr. Grierson had suggested that $2\frac{1}{2}$ usages per day was normal for cylinders that were intelligently selected with reference to the probable demand, and that figure was confirmed in the discussion on that paper.

Mr. Nobbs. Mr. W. W. NOBBS remarked that the subject covered by the Paper was so extensive that few people could have an intimate knowledge of every phase of it; his remarks would be confined to those portions of it on which he could speak with authority. He was in entire agreement with the Author regarding the fundamental differences between gas and electricity as agents for heat-production, and the Author was to be congratulated on the manner in which he had set out the advantages and disadvantages of the two agents. So far as his own experience of heating and hot-water service went, he was in general agreement with the Author's conclusions. Expert opinions had already been expressed on the subject of capital costs of generating plant and distribution. He thought that, in general, the Author had been lenient in putting the cost of installing electrical fittings at from three to five times that of installing gas equipment. His experience was that the higher figure was nearer the mark, but a great deal depended on the particular conditions applying to each individual installation.

A criticism which applied generally to the examples given in the Paper was that they were too extreme. Doubtless this was to emphasize the Author's points, but they might be accepted as conditions generally encountered in normal practice. He would suggest, for instance, that a 20-gallon bath drawn off in 6 minutes, requiring a power input of 30 kilowatts or a gas-consumption at the rate of from 200 to 250 cubic feet per hour, would be more convincing and applicable to actual requirements than the exaggerated example given by the Author of a bath requiring 20,000 B.Th.U., namely, 40 gallons of water, drawn off in three minutes; there were thousands of gas and electrically-heated instantaneous water heaters with practical ratings which gave reasonable satisfaction. He would also suggest that the first item in Table VI, the "very full hot bath," might have been omitted with advantage, or the rate reduced to more reasonable proportions. Adopting the temperatures used later in the Paper, that item inferred a 40-gallon bath, 30 gallons being heated to 130° F. and then cooled to 110° F. by the addition of 10 gallons of cold water; a bath temperature of 110° F. was too hot for the great majority of people. For much the same reason, he could exclude the last value given in Table VII; such an extravagant demand as 50,000 B.Th.U. per person per day for domestic hot water should not be countenanced by statistical reference. He thought that all the thermal demands noted in Table

VII, except that for a poor person, were rather exaggerated; this Mr. Nobbs. view was borne out, so far as it was applicable, by *Fig. 4*. If the latter were studied and compared with Table VII, the impracticability of applying general conclusions to individual cases without making provision for special conditions would be manifest. In his experience the most extravagant users of domestic hot water were the occupants of residential flats where a constant hot-water supply was available, but even in such cases he had found that a normal demand was met by the provision of some 25,000 B.Th.U. per person per day, and he would put the high value in Table VII at 30,000 B.Th.U. In other types of buildings the values would be correspondingly less.

Dealing with central heating, the Author put the primary efficiency of the conversion of electrical energy into heat at substantially 100 per cent., and for a gas-fired boiler at 80 per cent. The Author also put the efficiency of the whole boiler-installation, taken from heating-agent to water, at 85 per cent. for electricity and 70 per cent. for gas; namely, a further loss of 15 per cent. for electricity and 10 per cent. for gas. Since the installation, apart from the boiler-plant, was identical, it seemed necessary to account for the difference in the two figures. He would not have thought that the thermal-storage vessels, when carefully coated with heat-insulation material, would account for that 5 per cent. additional loss. The Author appeared to overstress the possible dangers of an electrical installation, saying that it "... might cause the immediate death of any person touching a piece of live metal." In a thermal-storage plant of the character under discussion the only pieces of live metal were the busbars, suitably guarded behind the switchboard, and the electrode-terminals, which were protected by a guard which could not be removed without automatically opening the main circuit-breaker.

In dealing with the distribution of heat, the Author referred to the hygienic disadvantages of electrically-derived heat in not requiring any ventilation, and he referred to the more pleasant conditions existing where a gas fire with a large flue caused the air in the room to be changed from five to ten times per hour. Except for lavatories, kitchens and similar rooms, that was a high rate of ventilation, and any ventilation-effect exceeding six changes an hour in a private room would render it uncomfortable.

Table XVI gave the results of experiments with different rates of ventilation in a room with a volume of apparently 2,000 cubic feet. Those results were exceedingly interesting, and would be even more so if the Author had been able to provide more data on which an analysis could be made.

Mr. Masterman. Mr. C. A. MASTERMAN said that the Author made repeated references to an imaginary low efficiency of gas appliances, which he variously attributed to heat-losses in the flue, inadequate insulation, ventilation of the room and other causes, and in *Fig. 2* he referred to the supposed losses; but whereas the ordinates in *Fig. 2* extended to 3,750° F., experience showed that from 500° F. to 600° F. was the maximum for domestic appliances.

The Author's intention appeared to be to compare gas and electricity for equivalent services. Many of Mr. Masterman's criticisms of the Paper arose from his disagreement with the Author's assumptions that he was setting out equivalent service-conditions. The only essential contrast between the two agents was that a gas appliance had to vent its products whereas an electric appliance could in some circumstances remain sealed. The significance of the heat-loss from a gas appliance due to that venting had been greatly decreased during the last few years owing to technical developments. Heat-loss from the flue of the ordinary domestic gas oven was now approximately half what it had been a few years ago, and was a fraction only of the loss through the lagging, which was of similar magnitude whether the cooker were gas or electric. It was interesting to remember that designers of electric cookers had now come to appreciate the need for venting the oven in the interests of good cooking, and that with modern cookers for equivalent cooking-service the loss in weight of the foodstuffs cooked was substantially the same for both gas and electrical cookers.

The Author stated that by the agency of electricity ". . . pure heat-energy can be delivered through flexible wires in any quantity, . . ." That claim the electrical engineer would be the first to contradict, since it was the limitation of supply which, after price, was one of his greatest handicaps.

In connection with water-heating, the most common application of gas was by means of an instantaneous water-heater, a system inapplicable in the case of electricity, since it would involve a loading of the order of 25 kilowatts. Similarly, the relatively slow operation of the electric hot plate was partly due to the limitations in loading, which corresponded to very little more than half the heat-energy in a normal gas-ring. Even so, the switching on of all the elements of an electric cooker corresponded to bringing into simultaneous operation more than twenty electric lamps. By turning down the gas supply to correspond to the heat-input of an electric hot plate, an increased efficiency was obtained, but most users valued the advantage of speedy operation, even at a slight increase in relative gas-consumption.

The Author referred to the use of gas geysers as involving consider-

able risk of accident, a claim which could hardly be reconciled with **Mr. Masterman**, the many tens of thousands of those appliances which were in daily use, and with the fact that fatalities from such appliances in five centuries would be less than the annual fatalities from road accidents in Great Britain.

The Author suggested that carrier-current control was peculiar to electricity, and suggested that gas was, in its nature, not susceptible to anything resembling this control. He was apparently unfamiliar with the fact that a number of cities, including Berlin, were largely lighted by gas all of which was under pressure-wave control.

The Author propounded the theory that if the products of combustion exceeded 212° F. condensation could not take place. Although perhaps of no great significance, that theory was wholly incorrect. It was a familiar fact that in many water-heaters, for instance, the products of combustion might be leaving the flue-outlet at from 300° F. to 400° F., yet condensation might occur and might be a nuisance.

Reference was made in the Paper to a reversed refrigerator-cycle as a means of heating. That was an interesting device which within a limited field had been successfully used, but it was a device which no electrical engineer would claim as peculiar to electricity.

Detailed comment upon the Author's references to lighting would perhaps be inappropriate, but his conclusions seemed to be incompatible with his own claim that gas was a cheap lighting agent, and with the experiences of the Gas Light and Coke Company, which reported a substantial addition last year to the number of gas street-lamps put into operation. The Author might be interested to learn that the average life of their mantles was not, as he had suggested, about 350 hours, but over 1,000 hours. In selected cases mantles had been found to give full light-value after 8,000 hours.

The Author's calculations of equivalent prices for gas and electricity for water-heating appeared to credit gas with a heat-transfer efficiency of under 60 per cent. ; in **Mr. Masterman's** opinion that was an under-estimate of about 20 per cent. It should be emphasized that, apart from the difference between gas and electricity in heat-transfer efficiency, there was no reason for any contrast in operating efficiency. It would be interesting to have the Author's explanation of his statement that a gas heater could not be so perfectly insulated as an electric heater. The Author's reference to the deposition of fur as being responsible for substantial reductions in efficiency in the case of gas-fired water heaters was not supported by evidence and experience. If pilot-lights existed which burnt about 1 cubic foot of gas per hour, that would represent a degree of waste if the heat were in no way utilized ; in practice, however, the normal rate for a

Mr. Masterman. pilot-light was of the order of 0.5 cubic foot per hour, and recent developments in pilot-light design suggested that an even lower consumption could be obtained without prejudice to stability. The Author's claim of 10*d.* per therm as equivalent for water-heating to 0.7*d.* per unit was approximately 50 per cent. in error, the electrical equivalent in fact being considerably less than 0.5*d.* per unit.

The Author's comparison of the two heating-agents for room-heating appeared especially to invite the criticism that he was comparing unlike services. If the Author were content with "stuffy" room-conditions, due to inadequate ventilation, then comparisons must be based on flueless electric heaters against flueless gas heaters, both types of appliances being now very familiar to the public. It would then be found that the equivalent of gas at 10*d.* per therm was electricity at about $\frac{1}{3}$ *d.* per unit. It would be generally agreed, however, that such a form of heating fell short of the ideal, and that, for conditions of true comfort, ventilation as well as heating was required.

The Author contrasted the ventilation from an ordinary 9-inches by 9-inches flue with the smaller types of proprietary flues used for gas fires. The measurements given in the Paper were incorrect; the dimensions of those flues were 12 inches by 2 inches, or 15 inches by 2½ inches, and not, as the Author stated, 10 inches by 2 inches. A very complete series of tests and calculations with such flues had led to the conclusion that, for a 30-foot chimney a 9-inch by 9-inch flue with a 5-inch chimney-pot would give 7,000 cubic feet per hour of additional ventilation; a flue 15 inches by 2½ inches would give 6,000 cubic feet, and a flue 12 inches by 2 inches nearly 5,000 cubic feet. The Author in the following pages appeared to suggest that the ventilation in the former case was wholly excessive, whereas in the latter the ventilation effect was negligible. In disregard of those figures, however, the Author had assumed that, with a gas fire an air-exchange of 10,000 cubic feet per hour took place, for the heating of which he had made an allowance of 25 cubic feet of gas. Such an allowance would lead to a temperature rise in the air exceeding 60° F., and would be intolerable to the occupants of the room. The Author's Tables, derived on that basis of calculation, appeared to be wholly misleading, and Mr. Masterman considered that the principle from which they were derived was false, since the warm vitiated air which passed up the chimney had already served its purpose; on hygienic grounds it was therefore desirable to remove it from the apartment.

In Table XIV there was a column representing the running costs for an electric fire, based on a radiant efficiency of 100 per cent. An efficiency of even 98 per cent. could not be obtained with a surface

temperature of less than $1,650^{\circ}$ C., which was not only impossible to Mr. Masterman. obtain but would also be intolerable in effect, even if dark glasses were worn.

The Author estimated that electricity at 0.7d. per unit was equivalent to gas at 10d. per therm for cooking. That estimate appeared to be approximately 50 per cent. in error, and he could only imagine that the Author had not made himself familiar with the developments in gas-cooking which had taken place over the last few years; or perhaps that the Author had exaggerated the developments in electric cookers. Inadequate information must have controlled the Author's reference to gas and electric furnaces. The Author's broad statement that the outside of an electric furnace was cooler than that of a gas-fired furnace seemed also to be based on an irresponsible estimate.

He would be the last to claim that any one form of heat-energy was ideal for all types; undoubtedly there were circumstances where electrical heating was truly economic. He believed, however, that there were many more applications for the use of gas. Industrialists were certainly recognizing that the higher throughput and smaller wastage obtained with readily-controllable fuels would often more than offset the higher price of the crude heat. The Author's suggestion that developments in thermal equipment were handicapped by unwillingness on the part of either the gas or the electrical industry to take advantage of the facilities provided by the other was quite unfounded.

The ground covered by the Author was important, and his Paper was of a type unusual to The Institution; it was all the more necessary, therefore, to draw attention to an undue number of apparent inaccuracies and to the possibility of the Paper creating false impressions detrimental to both the industries concerned.

* * Lieut.-Commander R. B. FAIRTHORNE observed that, in Table Lieut.-Commr. Fairthorne. XVII, opposite "Hot-plate cookery," comparative figures were shown indicating for electricity a superiority in assumed actual efficiency. This seemed at variance with the statement on p. 262 with reference to comparative heat-absorption from the surroundings.

Did not the Author wish to convey that there was a variable efficiency in the case of an electrically-heated hot-plate, which overtook that of its competitor only after a lapse of time had allowed the temperature to rise?

If that was so, he would ask the Author whether the figure for electricity in Table XVII represented the maximum or the mean

* * This and the succeeding contributions were submitted in writing.—SEC. INST. C.E.

Lieut.-Commr. Fairthorne. efficiency. Did it take into account the fact that “. . . the time occupied . . . with electric power is 70 per cent. greater than with gas” ?

Mr. Humphreys. Mr. O. W. HUMPHREYS observed that the Author was to be congratulated on his attempt to settle the long-standing controversy concerning the relative costs of gas and electricity for the purpose of heat-production. He had read through the Paper with considerable care, and had noted the very fair and impartial way in which the Author had enumerated the relative advantages of the two agents for heat-production ; he found it difficult to follow him, however, on the question of the determination of costs in connection with incandescent fires, and on most of his remarks concerning cookers.

The question of the allowance necessary for ventilation in comparing the costs of heating by gas and electric fires was admittedly difficult, but there seemed to be little justification for comparison on a basis of equal ventilation. If, as the Author implied, two changes of air would in general be adequate for a room of 2,000 cubic feet, the additional three or more changes produced by gas fires might lead to a feeling of slightly greater freshness, but they could not be given any monetary value. He suggested that the fairest comparison would be on the basis of the consumption of gas or electricity necessary to produce certain specified minimum conditions of temperature and ventilation. If two changes of air per hour were specified as a reasonable figure, it was clearly unfair to debit the electrical system with five changes merely on the grounds that gas could not heat the room with less changes. The cost of electricity and gas should be assessed on the basis of two and five changes respectively and the additional sense of freshness, or the increase in draughts, which resulted from the greater ventilation given by the gas fire should be allowed for when the incidental advantages and disadvantages of the two forms of heating were considered. As the Author stated, the use of a fan to assist ventilation in private houses and offices was rare. Neither was it necessary. Forced ventilation had its undoubted advantages, but if natural ventilation sufficed during the summer months for the room that, in the winter, was heated and ventilated by a gas fire, there would appear to be no reason why the same system should not be employed throughout the year in the case of an electrically-heated room. He therefore suggested that to obtain a fair estimate of the relative costs which were to be expected in practice under the general conditions postulated by the Author, allowance should be made for five changes of air per hour in the case of a gas fire and two changes in that of an electric fire, no fan being considered in either case. If Table XV

were adjusted accordingly, it would be seen that equivalent prices, Mr. Humphreys, including the provision of adequate ventilation, would be very nearly 1*d.* per unit for electricity compared with 10*d.* per therm for gas. That proportion agreed closely with the experimentally determined figure which the Author stated on p. 259, but to which no reference was made in Table XVII.

With reference to cooking it was stated on p. 262 that "the time occupied . . . with electric power is 70 per cent. greater than with gas." The Author must, he thought, have intended that statement to be limited to hot-plate cooking, for apart from preheating, which was admittedly quicker with gas, there should be no difference in the speed of cooking in an oven, and electricity was certainly as fast as gas for grilling purposes. Was the Author aware that several manufacturers were to-day producing, in very large quantities, electric hot-plates which would boil 2 pints of water (a temperature-rise of 85° C., with flat-bottomed utensils) in about 6 minutes, and 3 pints in 8 minutes ?

It was difficult to follow the Author in his contention that a cook understood a gas cooker more readily than an electric one, for the keynote of electric cooking was its simplicity. With a gas cooker, owing to fluctuations in gas-pressure and fouling of the burners, there was no permanent relation between tap-position and height of flame, whereas with an electric cooker only three switch-positions were provided, and in practice only two of those were generally required. Control was so simple that, although thermostats were fitted to gas cookers some years ago, there was as yet no indication that a demand for such assistance would arise from users of electric cookers.

In connection with cooking-utensils, it was true that, with one widely-used type of electric hot-plate, exceptionally fast boiling could be obtained by the use of flat-bottomed vessels. It was, however, very misleading to claim that their use was essential, as the majority of the users of this type of hot-plate were so satisfied with the performance obtained with ordinary utensils that they did not take advantage of special utensils. Further, so far as other types of electric hot-plate were concerned, flat-bottomed utensils offered no advantage whatsoever. In fact, the shortest boiling-times were frequently obtained with the ordinary vitreous enamelled-iron ware.

Concerning the cost of cooking, the Author stated that "In a prolonged series of trials . . . the amount of heat used in a gas cooker was from 50 to 100 per cent. greater than in an electric cooker," and in the next paragraph that "The relative cost of gas and electricity, taken over a long period, was found to be that electricity at 0.5*d.* per unit is the equivalent of gas at 10*d.* per therm."

Mr. Humphreys. On the basis of the Author's own tests, the equivalent price for electricity was, he believed, from 0.51 to 0.68 pence per unit, or an average of 0.6*d.* per unit. In view of the material improvement in the efficiency of electric cookers which, according to the Author, had taken place since the experiments were made, the figure of 0.7*d.* per unit, which he derived by calculation for modern cookers would appear to be too low. In any case, the inclusion in Table XVII of figures for cooking which the Author admitted to be out of date, was of questionable utility.

In the last paragraph of his conclusions, the Author must, he thought, have been chiefly concerned with the dwellers in small towns and rural areas. On the basis of the relative costs which the Author had put forward, very large numbers of consumers in and around the larger towns and cities were now buying electricity at prices which made it as cheap as, or cheaper than, gas, for purposes of heat-production. Their number was still further increased, if his deductions from the Author's statement with reference to incandescent fires and cooking were warranted.

Mr. Ryves. Mr. REGINALD A. RYVES drew attention to the words on p. 255, ". . . some convention in regard to the loss of heat through the excessive ventilation that is induced by a gas fire," and observed that, as relating also to the efficiency of a coal fire, consideration should be given not only, as the Author seemed to assume, to that efficiency in respect of the room, but also to efficiency in respect of the house, or to a room above it; the loss of heat, in that separately-considered computation, being measured at the chimney-pot. The heat transmitted by the column of air and gases in its passage through a chimney that presented from 100 to 140 square feet of lining was considerable and, per degree of rise of temperature, was of special importance, in that it reduced, in the upper storey, depreciation of the fabric of the house, the interior decoration (especially wall-paper), furniture, fittings and clothing. That was due to the effect in maintaining the temperature inside the house at a level slightly above (or less below than it otherwise would be) the air-temperature outside; the result was that when warm and moist air penetrated a house which had been chilled by a previous cold spell, the condensation of moisture on the walls, ceilings, and contents was considerably reduced, or even prevented, during the critical period which elapsed before the colder parts of the house attained the temperature of the outside air.

Mr. Verity. Mr. C. E. H. VERITY stated that, whilst appreciating the great amount of trouble that the Author had taken in evolving a theoretical basis for comparison, he was disappointed to find frequent statements that the conditions were so variable and the information available

so incomplete as to render any comparison only a first approximation. Mr. Verity. It appeared that the problem was rather more of a domestic one, and one that did not admit of detailed theoretical treatment, as the comparison was necessarily influenced by such matters as convenience—such as the use of electric light, æsthetic values—such as the preference for coal fires, and speed—such as the rapid heating of a gas cooker.

The Author tended to take the attitude that there was considerable rivalry and competition between the producers of gas and electricity, and referred to the commercial hostility between the two industries as being very acute. He thought that that was not the right attitude to adopt and that the two agents for the production of heat should be considered as complementary rather than as competitive, as there were many more important considerations than either the pure financial aspect or the relative efficiency of the processes.

It would be of assistance if the Author could give typical comparative heat-balances, indicating the losses incurred in the production of gas and electricity from 1 pound of coal of given calorific value, together with corresponding typical financial balances.

Considering the matter from a more national aspect, he suggested that the Author might show how the initial fuel could be most usefully employed in producing the various products required throughout the country, such as gas, electricity, coke, tar, oil, and petrol. There must be an optimum financial condition which would give the cheapest production of all those items in the proportion in which they were required by the general public.

The AUTHOR, in reply, ventured to deprecate the introduction into The Author. such a discussion of the “back-chat” that often figured in similar discussions in the technical press, as he had hoped to keep it on a somewhat higher plane. It was even less edifying to hear two great industries sneering at one another than to hear individuals indulging in personalities in public. The gas-holder was not an object of beauty, but neither was a row of pylons sprawling across a beautiful countryside; a heated argument as to their relative ugliness did not in any degree influence the user in deciding whether gas or electricity was the better for doing his work. There had also been mutual recriminations as to the degree of danger. As if to illustrate the observations made in the Paper and also the incongruity of such recriminations between the two industries, the daily press of a few days later gave an account of an accident in Leicester where three hundred people were driven out of their homes by an explosion due to a gas-leakage, and side by side with that account was another of an electricity breakdown in Bradford which stopped the whole of the supply to that large town for at least 24 hours. The use of

The Author. any such agent inevitably involved a certain degree of danger, but as Mr. Lacey had said, it was singularly small.

Compared with electrical energy any gaseous fuel had certain disadvantages and dangers, while high-grade energy like electricity could not be otherwise than expensive and liable to accident, and an argument on the question of which of those features was the more undesirable was not very edifying. The truth was that both electricity and gas were indispensable, and it was necessary to put up with the small disadvantages which their use involved. Both had drawbacks, some of which were inevitable. Those which were not inevitable should be remedied in the public interest. The object of the discussion was to help the public to choose with intelligence which was better in the circumstances for any service in which either could be used. There were examples in the discussion of distortions of the very careful language of the Paper and of misrepresentation of the figures given, with the object of scoring points in the interest of one industry or the other; it was difficult to see why such distortions should have been made.

Hardly any of the criticisms of the Paper were directed to its fundamental essence, but were largely on the accuracy of the figures which were given in the earlier part of the Paper relating to the cost of the plant and of the generation of the two agents, and also to the values given for the various efficiencies. Two important facts seemed to have been overlooked by the majority of the speakers, namely, that the first class of figures was prepared solely for the purpose of giving persons unfamiliar with those matters a general idea of the approximate cost of the plant and of the generation of the two agents, and not with the impossible object of laying down in a sentence complicated figures of universal application. Any one who studied the extremely involved published figures relating to the cost of the different power-stations and gas-works must have been struck by the wide variations between them, according to the cost of the land, the type of machinery installed, the quality of equipment and other features having little relation to their maximum output. In the same way the cost of supplying and laying cables and gas-pipes varied greatly between different cases. In a general Paper it was totally impossible to enter into a long explanatory discussion on those extremely intricate matters, and it would not be of the slightest use to an average reader of the Paper, who required only a general approximate idea of the magnitude of those costs, if it could be obtained. It seemed to have been overlooked that the precise accuracy of figures prepared for such a purpose, even if attainable, would have

been of quite secondary importance to the main object of the Paper, and hardly worthy of the prominence given to them in the discussion. The Author.

Similarly, a good deal of criticism had been directed from one side or the other against the values of the efficiencies given. Those criticisms largely counter-balanced one another. Such electrical authorities as Mr. Bernard complained that the Author had not been fair to electricity, while Mr. Masterman complained that the Author had not been fair to gas. Similar discrepancies were observed in regard to lighting efficiencies. It should have been perfectly obvious that, as the efficiencies of different makes of plant varied between themselves, and in a growing industry were continually being improved, the best values of to-day were likely to be better in both cases than those of yesterday, so that it was impossible to lay down any absolute values for permanent use.

Mr. Lacey had properly called attention to the fact that the acceptance of a Paper by The Institution invested it with an air of authority, which possibly in the present case might not be justified. The latter reservation was perhaps understandable from the point of view of gas, but he cordially agreed with the preceding remark. The language of the Paper and its statements had been accordingly prepared with the greatest possible care and in full appreciation of the fact that the subject dealt with involved large commercial interests. In spite of what had been said in the discussion he did not see any reason for withdrawing or even modifying any of the figures given in his Paper, which he knew were substantially correct.

The question had been raised as to the source of the various figures of the cost of generation and distribution and as to how they had been determined, and an explanation seemed necessary. He had re-examined the original calculations from which the figures had been drawn up when the Paper was first drafted, and had found the following explanations :—

The total recorded cost of a number of large generating-stations was obtained from various published sources of which he had now no record, along with their total kilowatt-capacity ; among others, particulars of the following stations were obtained :—Bristol, Newcastle, Brighton, Tonbridge, Glasgow, Tunbridge Wells and Hackney. The total kilowatt-capacity was then reduced to the equivalent of therms per hour, and a simple division gave the figures in the Paper ; the highest and the lowest of those were given, the remaining figures varying between those two extremes. It would be observed that in each case the total capacity of the equipment had been con-

The Author. sidered, and not the actual output. There had been great difficulty in obtaining any figures whatever relating to the cost of pipes and cables; nothing could be found in published records and no particulars could be given by either of the industries. The Author had applied to many engineers, including his friend Mr. Stephen Lacey, but the reply he had received in all cases was that it was impossible to give such figures since they varied so greatly between different cases. He was therefore limited to his own resources in the matter. He had approached colleagues in the electrical industry who had actually carried out such work, and contractors who had actually put in the pipes on behalf of the gas industry, and by that means he had ascertained the figures given for costs per mile. As no contradictory figures had been quoted he presumed that the figures given in the Paper were sufficiently accurate for the purpose for which they had been prepared.

It had been found to be totally impossible to obtain any general figures relating to the cost of electrical transformers and sub-stations, and they had no parallel in the gas industry. The costs seemed to vary so widely, to have so little relation to their thermal output and to depend so much on other features that it was even impossible to obtain a "middle" figure which would give a representative idea of the cost per 100,000 B.Th.U. distributed. An average figure would convey no information whatever. It was therefore impossible to give a bibliography relating to those figures, as had been requested by Mr. Donkin. The cost of equipping buildings with electrical cables and gas-pipes was obtained from the Author's own experience of installing systems inside buildings.

Criticisms had also been directed against the accuracy of the representative costs of production of gas and electricity as given in Table I of the Paper. Here again there was a very wide variation between the recorded costs of various stations; an average taken over a large number of stations would mean nothing, and would not be any more valuable for the purpose of general information than correctly representative figures. The figures actually given were well within recorded limits in all cases.

It would be observed that in all cases the approximate costs were given as a single digit, for the express purpose of indicating their approximate character, as any decimal places would have presumed a certain degree of accuracy. The figures for fuel-consumption per unit were obtained by calculating the figure from what was believed to be the most efficient installation in the British Islands, namely the Portishead station of the Bristol Corporation, in which

1 kilowatt-hour was delivered for a fuel-consumption of 1.15 pound. The Author. The cost of coal varied greatly, but a representative cost was taken as 12s. per ton; the fuel-cost per unit on that basis would be about 0.075*d.* That figure was then compared with the average of the total units recorded as having been generated in the United Kingdom, namely, about 13×10^9 . The total coal burnt was about 10×10^6 tons, from which it appeared that a general average consumption was 1.74 pound per unit generated, the cost of which at the same rate was 0.118*d.* per unit. From those two figures he concluded that a reasonably representative figure giving a fair idea of the cost of coal would be 0.1*d.* per unit. That figure was slightly below the average but was well above the best.

The other items of cost had been determined in a similar manner, and he saw no reason to doubt that the figures given in Table I gave as good a general idea of the approximate cost of generation as could be collated. The figures given in the various Tables had been calculated from data and efficiencies given in the Tables themselves, so that their origin could not be in any doubt. Since the figures of efficiency which were given in the Tables had largely been calculated, it would be easy for anyone to alter them if he so desired.

The representative figures for efficiencies of single fittings and heaters had in many cases been determined from his own tests and observations on commercial apparatus obtained for that purpose. What he had called the practical figures of equivalents had been obtained either from installations put in by himself, or by the very convincing method of turning his own house into a form of laboratory; he had employed the latter method for many years, actually using the various appliances in practical service and recording daily readings of meters installed and connected up for the purpose of obtaining the necessary information. It was almost unnecessary to add that the records had been made without the remotest trace of bias in any direction. It was clear that such comparisons could only be made one at a time between two specific pieces of apparatus, and if either apparatus were changed for one more or less efficient the results might be slightly different in some cases. In his own house many different types of apparatus, of exactly the type that the public would buy, had been tried. The figures given were what he believed gave the most accurate information obtainable.

Mr. Masterman, who spoke as a technical representative of the gas industry, seemed to think that the Paper should have given the figures obtained in his own laboratory—presumably from the most efficient appliances on the market—in the case of gas, compared

The Author. with the worst results obtainable in the case of electricity. Such partisan comparisons would have been entirely misleading in a Paper prepared for general use. The results as given in the Paper were such as would have been obtained by any member of the public who bought the apparatus in the open market and used it in the same way as it was used in the Author's house; in his opinion such results were far more reliable as a guide to the public than any laboratory tests could possibly be, for they incorporated all the causes of incalculable variation in general practical service to which attention was directed in the Paper.

The Author feared that Mr. Masterman could not be acquitted of distorting the very careful wording of the Paper in the interests of his own industry. He strongly deprecated such an attitude. Mr. Masterman said, for instance, that "the Author stated that by the agency of electricity . . . 'pure heat-energy can be delivered through flexible wires in any quantity. . . .'" He went on to say that the electrical engineer himself would be the first to contradict that claim. The Author would reply, in the first place, that Mr. Masterman had omitted reference to the following words—"The amount which can be supplied is rigidly limited by the capacity of the generating plant and cables"—which appeared in the next section, headed "*Disadvantages of Electrically-Derived Heat.*" He would also reply that his statement as it stood could not be contradicted, because in fact pure heat could be delivered in any quantity through flexible wires, naturally assuming them to be of appropriate size. To elaborate that point Mr. Masterman continued, with an example already quoted in the Paper itself, to illustrate his superfluous argument that the amount of electrical power which could be delivered through a given cable was limited by the size of the cable.

Mr. Masterman was equally unhappy in his assumption that the Author was unfamiliar with the fact that the pressure-pulse system of control was, or had been, in existence in various large cities. That fact was stated in the Paper, but without names. Before citing Berlin he would have been wise to make enquiries about that installation. The system was rarely installed now because it was generally unreliable. It blew the water out of wet gas-meters, caused flickering of jets, extinguished pilot-lights, and had other practical defects.

Again, Mr. Masterman charged the Author with "propounding the theory that if the products of combustion exceeded 212° F. condensation could not take place." That appeared to be a distortion of the wording of the Paper, "If the temperature is not reduced below 212° F. all the vapour passes away with the products. . . ." The latter was a perfectly accurate statement which

could not be denied, and was not a "theory propounded by the The Author. Author." In the cases quoted by Mr. Masterman the layer of gas in close contact with a cold surface in a gas appliance was actually reduced below 212° F., and therefore deposited condensation on the cold surface. He would have thought that a partisan of gas interests would not have emphasized that fact, as it was one of the grave drawbacks of the use of gas for such purposes.

Mr. Masterman stated that in Table XIV a column was based on a radiant efficiency of 100 per cent. That was a misrepresentation of the purpose for which that column was inserted, namely, to enable the reader to see at a glance what the cost would be in the limit if all the energy could be delivered as radiation. Nobody should know better than Mr. Masterman that a radiant efficiency of even 98 per cent. could not under any circumstances be attained at any temperature whatever.

Another mis-statement was that the Paper suggested that the average life of a gas-mantle was 350 hours. No such statement or figure was either given or implied in any part of the Paper, the only reference to the subject being that "The rate of deterioration of a good gas-mantle is about one-third . . ." of that of an electric bulb; that was true, and was in the exact opposite sense to Mr. Masterman's statement. Again, his statement that the accumulation of fur in a gas-boiler installation did not interfere with its efficiency would be very satisfactory information for all boiler-engineers if it were true, which it clearly was not. The Author most strongly deprecated that kind of criticism, especially when it was combined with indefinite charges of general inaccuracy.

Mr. Lacey, in the interests of the gas industry, emphatically protested against the Author's statement that the use of gas gave rise, along with the heat, to the emission of products of combustion which were mainly of a deleterious character. The Paper said that the use of any agent other than electricity (including coal, oil, wood and charcoal, as well as gas) gave rise to products of combustion. He would be a bold man who denied that in the main those products of combustion were of a deleterious character if introduced into the air in a room. If not, what was the object of providing a chimney for a gas fire or a geyser, thus wasting half the heat? Just as dirt was matter in the wrong place, so products of combustion in breathing-air were matter in the wrong place. Water vapour itself was deleterious when it made the atmosphere too humid, as it generally did. The sulphur content was always deleterious to fittings, and to such articles as piano-strings. Even carbon dioxide, accompanied as it usually was by a fractional pro-

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portion of carbon monoxide, would have to be considered as a deleterious product of combustion.

Mr. Bernard complained that Table XVII was a theoretical Table in which all the equivalents were calculated from assumed efficiencies and prices, and that due credit was not given to electricity for its various advantages, which were not represented in the Table. The Table was clearly labelled "Cost of heat only." If, in spite of the explanations given, it should be read in any other sense, the Author surely could not be criticized for that.

The Author was unable to agree with Dr. Fishenden that the point of view of initial coal-consumption provided a simple way of comparing gas and electricity. That consideration, important as it might be in the national interests, had surely nothing to do with the consumer, from the point of view of whom the Paper was mainly written. The consumer was only concerned with the prices at which he could buy gas and electricity respectively, which had little or no relation with the cost of the necessary coal. The Author had endeavoured to explain clearly in the Paper the reasons why elementary B.Th.U. calculations of the relative amounts of heat in gas and electricity had a very small bearing on the cost to the consumer. That fact was clearly much more in favour of electricity than of gas, and gas partisans were therefore apt to insist on the thermal comparison rather than on the facts of use, which it had been the effort of the Paper to explain.

The very interesting questions of the distribution of heat which she raised could not possibly be discussed in a Paper such as the Author's, which had already had to be severely curtailed in order to bring it within a reasonable compass.

Mr. Roger Smith had suggested that the statement was inaccurate that heat originally propagated as radiation was carried up the chimney. The reason for that was that heat originally propagated as radiation was absorbed by the surfaces on which it fell, and air coming in contact with surfaces so warmed carried away as convection heat originally propagated as radiation, which was ultimately therefore carried up the chimney by the current of warm air. The interesting question about the effect of those hot products in warming the walls of the house, and other questions relating to the desirability of various forms of heat, were beyond the scope of the Paper.

The Author could assure Mr. Dolby that there was nothing magical about the laws of thermo-dynamics. The installation at Bourne & Hollingsworth had been recently declared by the clients to have been entirely satisfactory to them, both from a technical

and an economical point of view, after 8 years of service. Mr. The Author. Dolby might be recommended to visit that store during very hot or very cold weather and to judge the matter for himself.

Lord Pentland's criticism was that the Author had not taken into his purview the probability of future alterations in the relative cost of the two agents, and had made no reference to the variable factors of diversity and load-factor. To deal in a prophetic manner with such intricate questions in so general a Paper would have extended it indefinitely.

Mr. Grierson, in his interesting contribution, complained that the Author had not taken as a representative figure the high value of the efficiency obtainable at Barking, but the Author thought that an exceptional value of that kind would be out of proportion in a general Paper. The question of the relative danger of the two agents in time of war had been dealt with by the Author in the original draft, but had had to be eliminated in the interests of brevity.

The efficiencies of the insulation on water-heaters were taken exactly as supplied from the laboratories of the largest makers of those appliances in the British Isles. Mr. Nobbs criticized some of the figures of heat-consumption for hot-water supply as being excessive, and characterized 50,000 B.Th.U. as wholly excessive. The figures were ostensibly given as being the maximum that any engineer need provide, the large figure of 50,000 B.Th.U. having been taken from a very careful measurement of the Author's personal use of heat in his own house. It might be admitted that it was one of his few extravagances.

Commander Fairthorne appeared to have misconceived the meaning of the expression "efficiency" as applied to a cooker. The efficiency had either to be taken from cold or in the steady states, the two having little relation to one another. The figures in Table XVII represented the efficiency from cold, as observed on an actual apparatus.

Mr. Humphreys realized the difficulty of comparing agents so different as gas and electricity in the case of room-heating when the very involved questions of ventilation were taken into account. The making of comparisons did necessarily involve some attempt to ensure that the same conditions were obtained in the two cases. The experimentally-equivalent values of 10*d.* and 1*d.* for a gas fire and an electrical heater were quite definite in the Author's mind; his own study was equipped both with gas and electrical power, and frequent changes were being made even at present between the two installations, while observations were continually being made.

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No accurate measurements of the equality of the heat delivered could be made continuously, the quantities measured being the costs of gas and electricity respectively when they were used to give reasonable comfort to different persons using the room. In reference to Mr. Verity's request for heat-balances, that was an extremely involved question, and nothing of the kind could be given within a reasonable compass.
