An HVAC Engineer's Approach to Understanding Global Warming

Part 2 of 2

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Modeling and Simulation

It can be seen that there are large number of parameters involved, interacting with each other in various heat transfer processes with the changing values of their properties with time; moreover, many of the parameters do not vary linearly, some of them change not only in magnitude but also in their sign – for example, aerosols and clouds. It is a crucial requirement that feedbacks from the various components, that is to say, the current values of the temperature of the earth and composition of the atmosphere, temperature and composition of the ocean water, forest and land characteristics . . . the various properties of the components. . . all need to be factored in the calculations. In other words, the effect of interaction of the components needs to be taken into account. All these requirements make for an extremely complex scenario, especially from the point of view of projecting the future climate – like for example, the carbon di-oxide concentration and the temperature of the earth (for various scenarios). All information and data being discussed have been obtained by elaborate calculations using large and powerful computers. More information and more calculations – and better models with greater accuracy lead to better and greater information and so on – this cycle needs to be repeated endlessly.

It is only by using climate models and simulations on computers that we can learn about climate change in the coming years, decades and centuries.

The model simulations depend on assumptions about emission of GHG due to human activities; they, in turn, depend on assumptions about many factors involving human behavior. One can start with a set of descriptions of likely future emissions of Green House Gases. These will depend on aspects of human behavior and activities including

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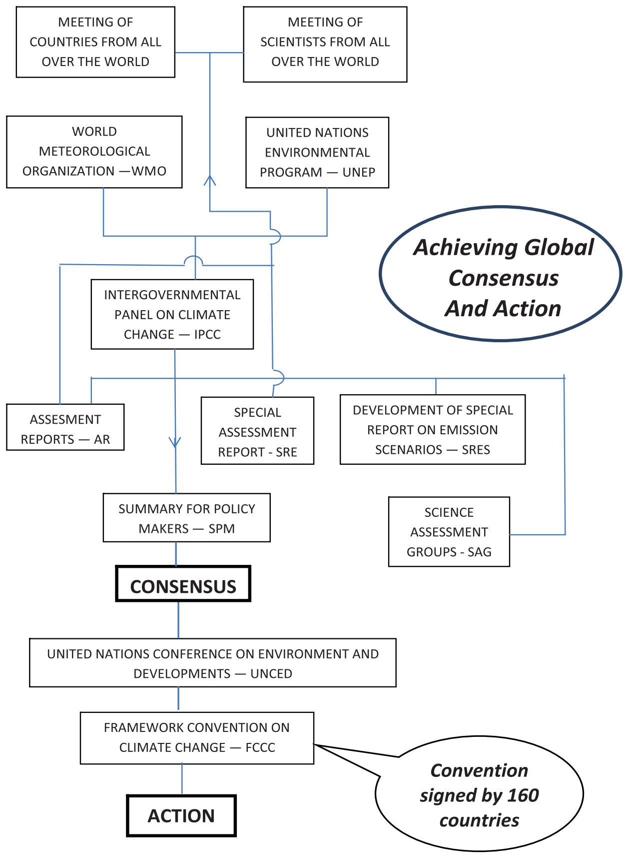
Emissions - IPCC's Special Report Emission Scenario (SRES)



From the "objective" of the climate Convention:

...objective of this convention and any related legal instruments that the Conference of the Parties may adopt is to achieve, in accordance with the relevant provisions of the Convention, stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development and to proceed in a sustainable manner.

This "objective" transforms to optimized stabilization levels worked out and projected by IPCC.

Figure 8: IPCC's Special Report Emission Scenario

population, economic growth, technological innovations, and attitudes to social and economic sustainability, energy use and resources of energy being generated. The description of all these aspects is called a 'scenario' of the environment. A large range of scenarios has been developed for providing options for selection of acceptable stabilization scenarios. All this work has been carried out by IPCC (please see *Figure 8*). The significance of the figure is first that the entire work has been carried out by a large number of scientists and with the involvement of scientists from virtually all countries of the world, and secondly that it has worked with the cooperation of again virtually all countries of the world and carries their approval. This process serves to provide the kind of credibility which is so necessary to achieve consensus amongst the people of the world.

(Earth) Temperature as proxy to assess impact of Climate Change Vs. Time

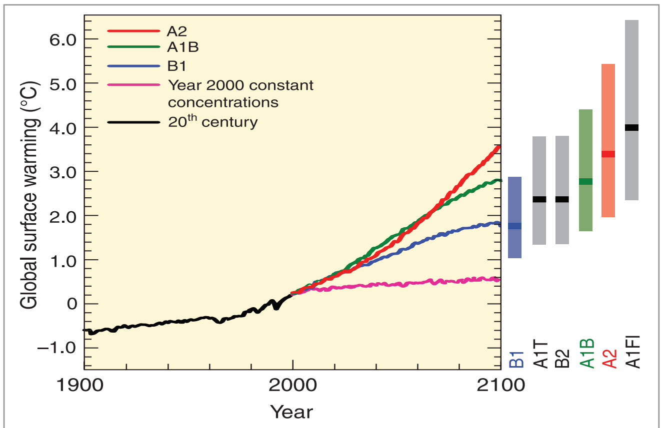


Fig 6.4 (a) Global averages of surface warming (relative to 1980-99) for the SRES scenarios A2, A1B and B1, shown as continuations of twentieth-century simulations. Each curve is a multi-model average from a number (typically around 20) of AOGCMs; shading denotes the one standard deviation range of individual model annual means. A curve is also shown for a scenario in which greenhouse gas concentraions were held constant at year 2000 values. The grey bars at the right indicate for year 2100 the best estimate and likely range of the six SRES marker scenarios taking into account both the spread of AOGCM results and uncertainities associated with representations of feedbacks. To obtain temperature increase from pre-industrial times, add 0.6°C.

Figure 9: Global surface warming vs. year

Figure 9 shows the Global Surface Warming vs. Year. In arriving at the earth temperatures in this figure, the variation and impacts of all factors like CO_2 emissions from all sources like greenhouse gases (major as well as minor) from all kinds of fuel and other energy sources, impacts of climate change like rise in sea level, melting of ice, temperature rises, cloud impact, changes of aerosol content and strength . . . have been factored. Note also in particular that the reference year in this figure is 2000, at which point the Global Surface Temperature is assumed to be 'zero'. The Global surface warming temperature at that year is 14.45°C.

Variety of Scenarios

In assessing the severity of impact of climate change and in projecting the parameters in various IPCC scenarios also it is the global average (surface) warming temperature that is used as a proxy, since it is the parameter that has the greatest impact on the climate. That is the reason why *Figure 9,* which shows temperature on the vertical axis, has been selected for inclusion in the article in preference to other parameters.

IPCC scenarios are based on a set of 4 different storylines within which each family of 'scenarios' has been developed leading to a total of 35 'scenarios'. The description of the B2 storyline is reproduced below as a sample.

B2 Storyline

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability. It is a world with a continuously increasing global population, at a rate lower than in A2, intermediate levels of economic development and less rapid and more diverse technological change than in the B1 and A1 storylines. While the storyline is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Six Illustrative Scenarios

From the total set of 35 scenarios, an illustrative scenario was chosen for each of the six scenario groups A1B, A1FI, A1T, A1, B1 and B2. All should be considered equally sound. It is mostly for this set of six illustrative scenarios that data are presented in this chapter.

The Dilemma - Should we Stabilize Increase of Earth Temperature at 2°C or 3°C?

Emission and Stabilization Scenarios

Figure 10 depicts a flow diagram showing the various players involved in the Global Warming/Climate Change impacts and their interactions; it helps understand the various steps/processes that lead to the optimum earth stabilization temperature.

It is obvious that climate change cannot be stopped instantly. Global carbon dioxide emissions have been rising all the time for more than 3 centuries now and are still rising and – moreover at higher rate (See *Figure 11* for temperature rises from 1940 to 2100 together with related impacts on GHG concentration stabilization level and global average surface temperature.) That is why we need to focus on bringing down the rate of emissions rather than stopping. If the rate is too high, the various steps of mitigation actions to be taken will get too harsh and too crowded. The cost of mitigation will be high and the weaker countries will find it too difficult to undertake. On the other hand, if the rate becomes too low, the signs and beginnings of the improvements in the scenario will appear too late; also, the harshness and durations of the impacts of climate change until mitigation action taken begin bearing fruits. It will be so long that global populations would experience acute suffering for unsustainably long periods. The rate need not be constant either - it can be revised from time to time.

It is widely known that the target for limiting the increase of global average surface temperature currently being talked about is 3°C (the reference value for the temperature itself being the pre 1750 value – about 13°C). The target was 2°C a few years ago, but it has been raised to 3°C recently essentially because mitigation action involved will be too expensive in a short run and too harsh for the present generations. However, opinion is veering towards cutting it down again to 2°C. The debate is about whether 2°C target is achievable and whether 3°C is too high. Those who stand for 2°C argue that it is achievable keeping in view the contributions expected towards reductions in emission throughout the present century from aerosols, cloud radiation activity, methane... will be realized. But there are various uncertainties

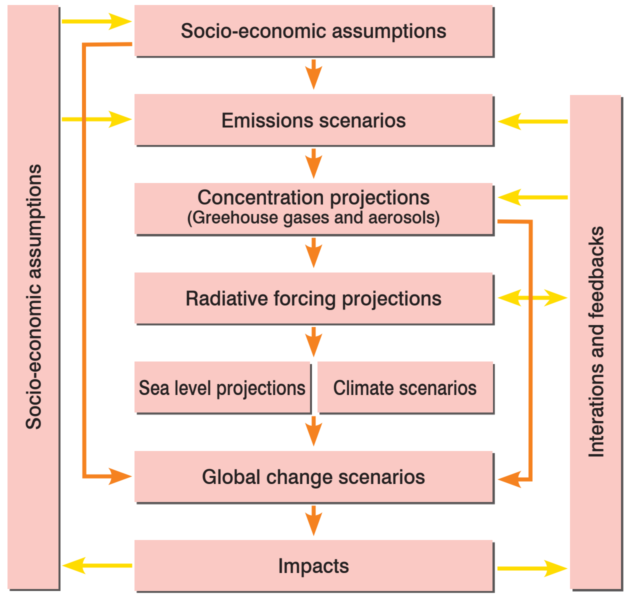


Figure 9.1 *The cascade of uncertainities in projections to be considered in developing climate and related scenarios for climate change impact, adaption and mitigation assessment.*

Figure 10: Players involved in global warming

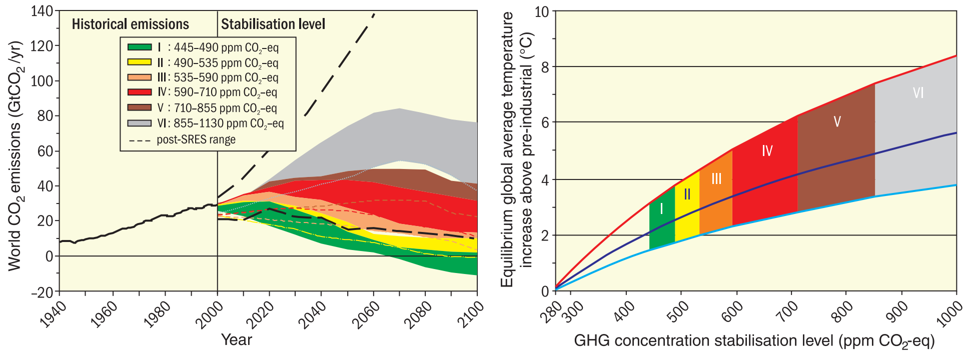


Figure 10.2 (a) Global carbon dioxide emissions for 1940-2000 and emissions ranges for categories of stabilisation scenarios from 2000 to 2100; colours show stabilisation scenarios grouped according to different levels (categories I to VI in inset and Table 10.3). The range shown covers the 10th to 90th percentiles of the full scenario distribution (numbers of senarios included in Table 10.3). The thin dashed lines denote the lower end of the range for that category in cases where there is overlap between the categories. To convert Gt CO_2 to Gt C_+ divide by 3.66. The thick dashed black lines indicate the range of emissions scenarios published since 2000. (b) Relationship between stabilisation level and the likely equilibrium global average temperature increases above pre-industrial level; the dark blue line assumes a best estimate of climate sensitivity of 3°C and the colours indicate the effect of a range in climate sensitivity from 2 to 4.5°C. For calculating the equilibrium temperature, the simple relationship T_{eq}-T_{2xCO_2} x ln([CO_2])/280/ln(2) is employed with mean, lower and upper values of $T_{2\text{-}CO_2}$ of 3, 2 and 4.5°C. The relationship between radiative forcing (R in Wm-2) and concentration (C in ppm) is R = 5.3ln (C/C_0) where C_1 is the pre-industrial CO_2 concentration of 280 ppm.

Figure 11: Temperature rise from 1940 to 2100 (projected)

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in several aspects which have not been figured in the calculations in the first place; secondly, the benefits assumed from contribution of sulphates (aerosols) may not be realized if sulphur dioxide emissions are reduced in order to avoid acid-rain. Considering these factors, chances of achieving a 450 ppm target (i.e., 450 ppm/ 2°C increase) will be 50% only. The same remark applies to the 550 ppm/3°C increase in target. In this background, the targets could undergo revision.

Sharing the Burden of Global Emission Cuts

The allocation of shares of the burden shown in *Figure 12* does not represent final commitments (and will be negotiated); it however provides a concept and a model based on which progress can be made.

So, the Dilemma – should we stabilize earth temperature at 2°C or 3°C? – still remains unsolved.

From Science to Engineering and Enforcement

At this point, we have crossed the bridge from science to HVAC engineering.

Science has given enough information for action to be taken at various levels, like taking all the countries on the globe and the governments engaged in debating for division of the emission targets amongst the various countries. Each country is working out its own commitments sector wise and so on to arrive at the country wise and sector wise targets. This is, of course, just a single sentence, but it will perhaps involve a great deal of tough negotiations, give and take at every level - international, national, region, state... down to the operating level. *Figure 12* furnishes the break-up down to country level and not just that either. The targets for anytime can be worked out.

A rough calculation based on *Figure 13*, yields a Gt C per annum of 4.2 in the year 2030 for India. In the present scenarios, the targets will be revised, but the concept shown and illustrated by the proposal of Global Commons Institute will provide an interesting methodology for our studies.

Figure 14 shows the ASHRAE goal of net zero energy and carbon by 2030. Note that the graphic is presented with energy consumption on the vertical ordinates and not in terms of emissions.

No other text or description accompanies this figure.

Useful conversion factors: 1 ppm CO_2=2.13 Gt C;1 Gt C=3.664 Gt CO_2.

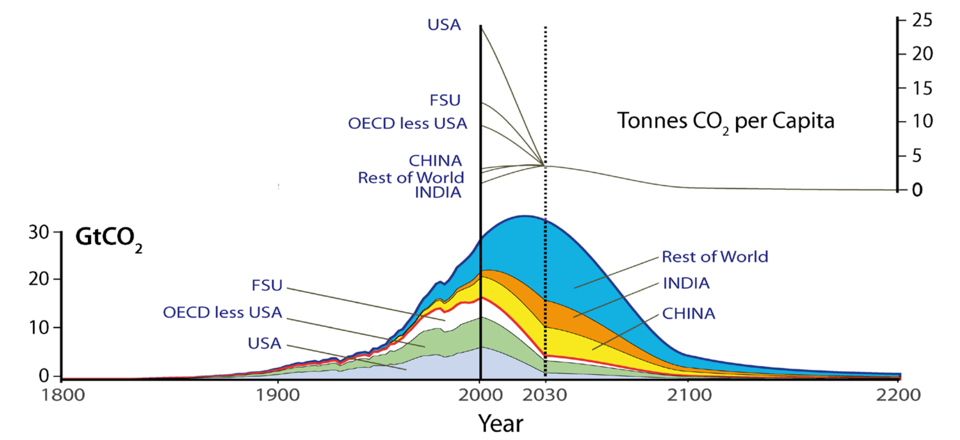

Figure 10.5 The 'Contraction and Convergence' proposal of the Global Commons Institute for achieving stabilisation of carbon dioxide concentration. The envelope of carbon dioxide emissions illustrated is one that leads to stabilisation at 450 ppm (but the effect of climate carbon-cycle feedbacks is not included). For major countries or groups of countries, up to the year 2000, historic emissions are shown. After 2030 allocations of emissions are made on the basis of equal shares per capita on the basis of population projections for that date. From now until 2030, smooth 'convergence' from the present situation to that of equal shares is assumed to occur. In the upper part of the diabram the per capita contributions that apply to different countries or groups of countries are shown. For OECD and FSU see Glossary.

Figure 12: Shares of burden of global emission cuts

HVAC to Come out with Plant Emissions Rather than just kWh

It is necessary to note that the targets will be expressed in emissions – Gigatons C (Gt C) or Gigatons CO_2e (Gt CO_2e) per

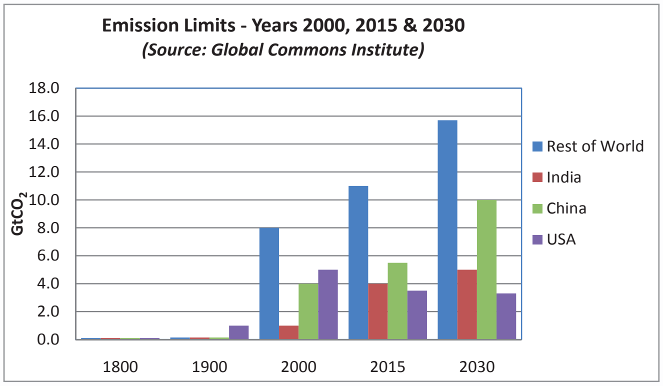

Figure 13: Emission limits

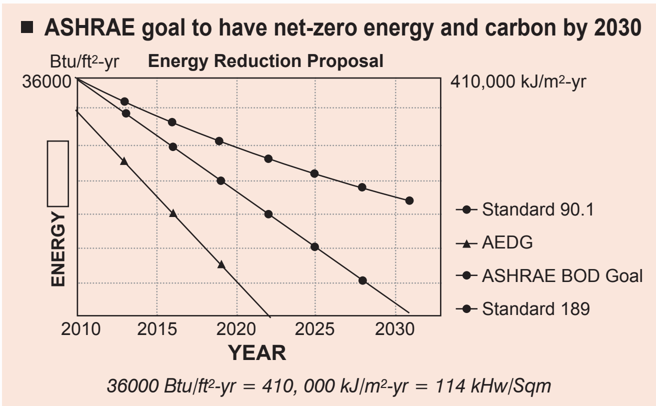

Figure 14: ASHRAE Goal – Net-zero Energy and Carbon by 2030

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year. Engineers need to work out the permissible maximum emission targets imposed on them for their projects. The HVAC engineers will need to do the same. The engineers need to convert the targets to kWh and design, plan and execute the work and run their plants on that basis. This is a top downwards approach. In practice, the kWh required by the equipment will be determined by the HVAC engineers (preference for emissions over kWh is probably because there are emissions which occur without the involvement of kWh; examples are agriculture, forests and plants, aerosols, cloud,...). As of now, his responsibility ceases from the design point of view with kWh. However, the requirement is that at the project levels and higher levels & for discourse at such levels, it is only the emissions that matter and not the kWhs. In fact, in the selection of driving equipment, the carbon dioxide emission for kWh would also play a crucial part. Also involved are losses in drive, cables and switchgear, transformers at site, transmission lines, distribution and again losses in cable, switchgear, losses in power conversion equipment (i.e., turbo alternator sets – in case of steam plant – diesel generators), transformers, switchgear and auxiliaries, all water systems, fuel pumping systems and whatever auxiliary equipment is used relating to this chain. The energy used by all these equipment should be loaded on the energy consumption of the HVAC plant. At each step, however, power lost must be calculated separately and the individual applicable emissions expressed in terms of Kg CO_2/kWh/year. The emissions thus calculated should all be added. It will no longer suffice to talk of just kW/TR. One manufacturer declares the emission based on a) the power generation losses – conversion from fossil fuel to thermal power followed by thermal power to electrical power losses, and b) switchgear and transmission losses, distribution losses. Item a) will depend on the location of the power plant and fuel used. A suitable multiplier will be provided by the manufacturer. Item b) will be calculated by the engineers. Results of such calculations obtained from a large number of installations in the applicable region will be studied and an appropriate factor determined and applied in selection of the plant for the project. Engineers are working on these concepts and improving them all the time. Appropriate software and other tools are also being developed (abroad). Please see References #6 to #9

Power – Scarcity and Poor Quality

It is well known that nearly 80% of the power generation of the country is from coal; even more importantly, the efficiency of conversion (fossil) of energy in the fuels to thermal energy is also low. The transmission and distribution losses are extremely heavy. As a result, a multiplier that has to be applied to convert kW/TR values into emissions is comparatively high. The value of the multiplier for India is 1.333 as compared to Singapore (0.579), Switzerland (0.0032), UAE (0.9328), US (0.547), and World (0.623).

The example below illustrates one way of arriving at emissions starting from the conventional point i.e., kW/TR values.

Sample Calculations for Emissions – kg CO_2/Year

Sample calculations for emissions for a centrifugal chiller are shown in *Table 2*:

Table 2: Sample calculations for a centrifugal chiller

Inputs	Option 1	Option 2
	R-123 centrifugal	R-134a centrifugal
Full load Tons	500	500
Refrigerant charge (lbs)	900	1250
Full load power (kW/ton)	0.448	0.512
Leakage rate (%/year)	0.50%	2.00%
Service life (years)	23	23
GWP (lbs CO_2/lb)	76	1320
Equivalent full load hours (hrs)	2500	2500
Carbon dioxide emission from power gen (lb CO_2/kWh)	1.486	1.486
Outputs (emissions in lb CO_2/annum)		
Indirect effect (CO_2)	191,39,680	218,73,920
Direct effect (CO_2)	7,866	7,59,000
Emissions :		
lb CO_2/annum	191,47,546	226,32,920
kg CO_2/annum	**86,83,412**	**1,02,66,111**

*The equations used for calculating emissions are : a) Direct Effect (lbs CO_2)= Charge (lb) * make-up rate (%/year) * service life (years) * GWP (lb CO_2/lb); b) Indirect Effect (lbs CO_2) = power (kW) * operation (hrs/yr) * service life (years) * electricity carbon dioxide(lb C)2/kW-hr*

Creating and Promoting Awareness Throughout the Hierarchy

Apart from defining a way of showing how new procedures of calculations are involved and describing a way of how they could be carried out, it is necessary to mention that there are mitigation considerations like, for example – renewable energy, development of new technologies, improving existing systems and finding new systems, applications of adaptive comfort approaches, low energy air cooling (and air conditioning) systems, *et al* to be looked into all the time. These points are not being covered in this article since engineers are familiar with these topics and also keep themselves abreast of developments on a day-to-day basis. However, the need for greater understanding of the phenomenon of Global Warming and climate change and their impact on HVAC... debates on related issues at various levels, sector-wise and region-wise, planning appropriate design and execution of projects to committed schedules, creating/increasing and promoting awareness amongst not only the stake holders (as generally recognized), but also amongst governmental organization, stake holders outside the industries and general public is the need of the hour.

Who is Doing What?

In our country - to the author's knowledge - The Energy Research Institute (TERI) and perhaps the Indian Green Building

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Council (IGBC) are working on all aspects relating to Global Warming, climate change, sustainability – there may be others too. But it does seem that many of the stake holders are aware of the concepts, approaches, procedures, design, calculations..., but the number is too meager. The message has not percolated down the line to those who are actively involved in the project work. Please see Reference #11. IPCC is keen to diffuse knowledge to the maximum extent. That does not seem to be happening in India. Given the targets from IPCC for emissions for our country, the break-down figures there-from, for emissions (energy usage) state-wise, linked at the same time to an agreed time-table could be worked out. Further break downs of the targets could follow, in turn, to various sectors like transport, agriculture... and of course, buildings. Also, break downs could similarly be worked out to any detail required for execution of work. This will give us targets we need to achieve. It will also help us to check whether enough is being done and fast enough from the point of view of meeting the targets set by IPCC. It is not clear whether the building sector – and more specifically, the building services sector or any other agency (ies) in this country – has been engaged or is engaged or will be engaged in this exercise.

The Last Word – A Challenging Situation

What is to be done? How is it to be done? When is it to be done? Who is doing what?... are all fundamental questions. The last word is that a great deal remains to be done, but that there are as yet no action plans ready. It is indeed a challenging situation.

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