Energy and urban form

Philip Steadman

The recognition by scientists and politicians of the seriousness of the greenhouse effect and the likelihood of global warming brings renewed urgency to the need for energy conservation. Issues which were on the research and policy agendas in the '70s after the OPEC shock of 1973/4, and then seemed to recede again during the `80s as oil prices stabilised. are now back with a vengeance.

The Toronto conference on *The Changing Atmosphere,* held in 1988, and the Inter-Governmental Panel on Climate Change, have both called for global emissions of carbon dioxide to be cut by *20'7(* by the year 2005, just ten years from now. It has been argued that, to achieve the global goal. much larger percentage cuts than this will be required from the developed nations. This graph (1) shows current levels of carbon dioxide emissions worldwide, and the rates of change needed to limit global warming to an increase of one tenth of a degree centigrade per decade.

These targets have startling implications for the use of fossil fuels, and hence for urban planning and the built environment. In Britain, for example, if present trends continue, then emissions of CO' are predicted to increase by nearly 40% in the next fifteen years. In those countries. like Britain, which rely heavily on coal, gas and oil for power generation and space heating, there are serious implications for the use of energy in buildings. And in all industrial countries there are major implications for energy use in transport. above all for the use of petrol in private cars.

I would like to show you briefly some statistics relating to current patterns of energy use in Britain, and the emissions of carbon dioxide which result. I appreciate that the British situation may be rather different from that of Spain. But these figures will perhaps serve to show you the context for some research work on urban form and urban density that we have been doing, which I hope may be of more than just local interest.

This table (2) shows the amounts of energy used for different purposes in the United Kingdom, including uses in the energy industries themselves, for 1988. broken down by type of fuel. Some of these figures are worthy of special comment. Notice in the energy conversion industries the very heavy use of coal and oil for producing electricity. A large fraction of the chemical energy content of the fuels is effectively wasted —it is lost as heat to the atmosphere— during this process. Some of this waste could in principle be put to good use in combined heat and power or district heating schemes. which would have significant implications for patterns of land use and for densities of development.

Energía y configuración urbana

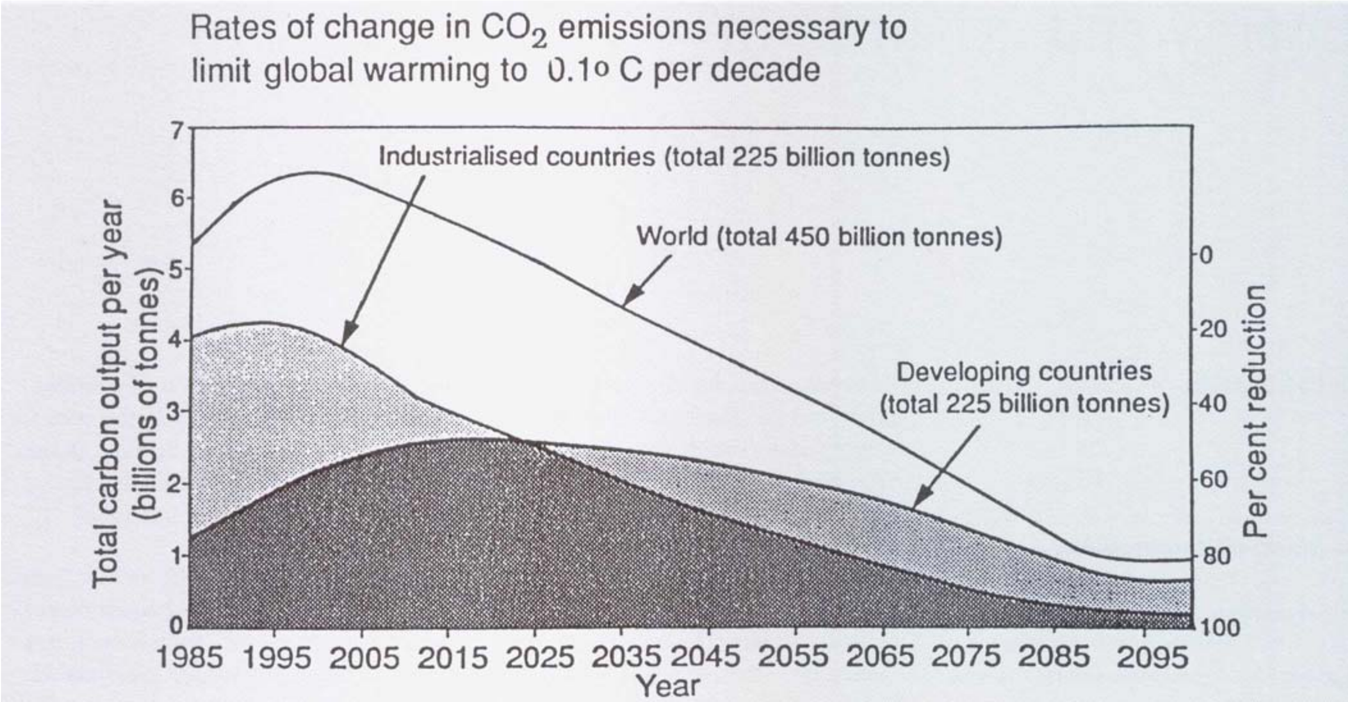
El reconocimiento por parte de los científicos y políticos de la gravedad del efecto invernadero y la probabilidad de un calentamiento global, hace cada vez más urgente la necesidad de conservación de la energía. Algunos de los temas incluidos en los programas de investigación y desarrollo del decenio de 1970 tras la crisis de la OPEP en los años 1973/4 y que en el decenio de 1980 parecieron caer en el olvido con la estabilización de los precios del petróleo, han vuelto ahora a cobrar protagonismo.

Tanto la conferencia de Toronto sobre *El sabio atmosférico* celebrada en 1988, como el Panel Intergubernamental sobre el Cambio Climático, han recomendado que las emisiones mundiales de dióxido de carbono se reduzcan en un 20'7í de aquí al año 2005, lo que supone tan sólo un período de diez años. Se ha dicho que, para conseguir ese objetivo global, los países desarrollados tendrán que reducir las emisiones en un porcentaje mucho mayor.

Estos objetivos tendrán grandes repercusiones en el uso de combustibles fósiles y, por tanto, en la planificación urbana y el entorno de los edificios.

Me gustaría mostrarles rápidamente algunas estadísticas referentes a las pautas actuales de consumo de energía en Gran Bretaña y de las consiguientes emisiones de dióxido de carbono. Soy consciente de que la situación en Gran Bretaña puede ser bastante diferente a la de España. No obstante, estas cifras les servirán posiblemente para conocer el contexto de algunos trabajos de investigación sobre configuración y densidad urbanas que estamos realizando y que espero que tengan interés más allá del ámbito local.

En realidad, una gran parte del contenido de energía química de los combustibles se desperdicia



Energy industries	*Coal, coke, solid fuel*	*Gas*	*Electricity*	*Oil*	*Total*
Refineries	0	0	0	230	230
Electricity	2036	9	0	229	2274
Coke ovens	64	0	0	0	64
Manuf. fuel	18	0	0	0	18
Total	2118	9	0	460	2586
Final users					
Iron & steel	230	47	29	35	341
Other indust.	234	524	288	392	1436
Transport	0	0	12	1888	1899
Domestic	250	1082	333	102	1766
Public admin.	34	131	68	113	347
Agriculture	0	3	15	38	57
Misc.	13	182	176	59	429
Total	760	1969	920	2626	6275
Gross	2878	1978	920	3086	8862

1. Rates of change in CO' emissions necessary to limit global warning to 0.1°C per decade.
2. Energy use in the United Kingdom (petajoulos), 1988.

1. Tasas de variación de las emisiones de CO' necesarias para limitar el calentamiento mundial a 0,1° por década.
2. Consumo de energía en el Reino Unido (pentajulios), 1988.

Among the end uses of energy there is a major use of oil in transport, as would be expected, and substantial use of gas, electricity and other fuels in the domestic sector, principally for space heating and water heating. A large part of the energy used in the "other industry". "public administration" and "miscellaneous" categories is also devoted to the heating, lighting and servicing of commercial and industrial buildings.

The fuel used in the energy industries can be allocated to the relevant end uses, and appropriate multiplication factors can be applied to the different fuels, to arrive at estimates of emissions of carbon dioxide (in millions of tonnes) for each end use. This table (3) presents the picture for 1988. Transport accounts for 24% of all carbon dioxide emissions, the domestic sector for 30%, and the service sector for 16%. If the emissions are broken down by purpose, it emerges that approximately 45% of all emissions are associated with space heating, water heating and lighting, all of which may be affected by building design. (The remaining categories are made up largely by the generation of process heat for industry, and the use of electricity and other fuels to power fixed machinery of all kinds).

The energy use sector which is most directly and significantly affected by urban planning and the distribution of land uses is of course transport. This pie-chart (4) shows the breakdown of the use of petrol by different modes of travel in Britain in 1987. What is striking is the large proportion, nearly 50%, taken up by priyate cars

	Space heating	Water heating	Lighting	Process heat	Other	Transport	Total (Mt)	%
Domestic	97	32	6	0	41	0	176	30
Iron & steel	0	0	0	0	36	0	36	6
Other industry	12	12	4	79	43	0	152	26
Services	44	8	27	0	16	0	95	16
Transport	0	0	0	0	0	134	134	24
Agriculture	0	0	0	0	7	0	7	1
Total (Mt)	153	52	37	79	136	134	593	
Total (%)	26	9	6	13	23	23	100	

3. Carbon dioxide emissions (Million tonnes) in the United Kingdom by end use (1988).

3. Emisiones de dióxido de carbono (millones de toneladas) en el Reino Unido según el uso final.

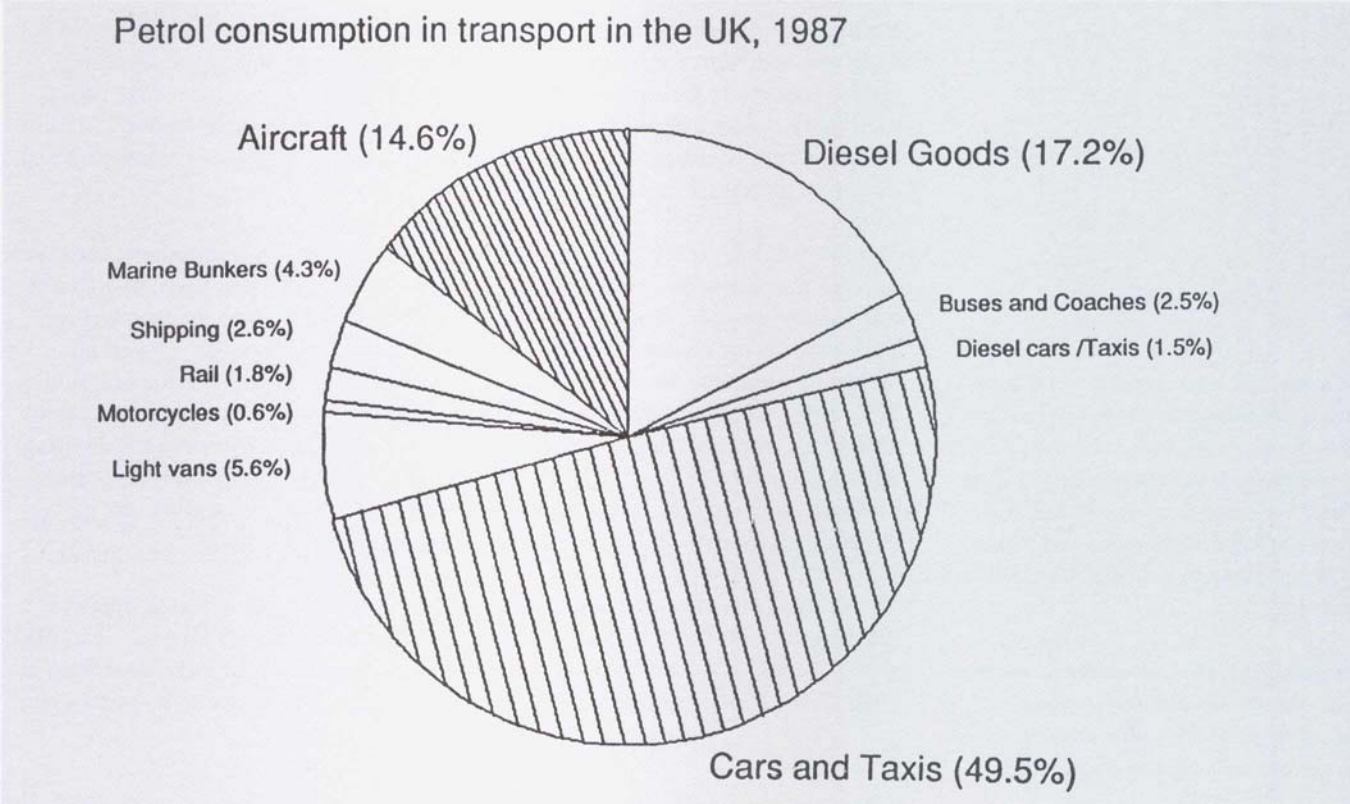
—se pierde como calor liberado a la atmósfera— durante este proceso. En principio. la energía desperdiciada podría aprovecharse de forma positiva en sistemas combinados de calefacción y electricidad o en sistemas de calefacción de distrito. lo que tendría importantes repercusiones en las pautas de explotación del suelo y las densidades del desarrollo.

Por supuesto. el sector consumidor de energía que se ha visto afectado de forma más directa e importante por la planificación urbana y la distribución de los usos del suelo es el transporte.

El aumento del consumo de energía en el sector del transporte ha estado causado principalmente por el aumento de las distancias medias recorridas al día o a la semana por la población. Esta tendencia a un uso cada vez mayor del automóvil está causada por, y es causa *de.* los procesos de descentralización que han tenido lugar en Inglaterra durante el período: descentralización a escala regional, desde Londres y por toda la región sudeste del país: y descentralización a escala urbana de las zonas residenciales a los suburbios y pueblos. del empleo a los "parques empresariales" y "parques industriales", y de las compras a los centros comerciales situados a las afueras de las poblaciones y supermercados suburbanos.

Según un estudio reciente, en un futuro relativamente próximo se fabricarán automóviles con motores de gasolina o diesel cuyos niveles de consumo de combustible en condiciones normales de conducción apenas llegarán a 25 kilómetros por litro.

Existen ciertos indicios de cambio en las pautas de trabajo. compra y educación que *podrían* reducir presumiblemente el consumo de combustibles para fines de transporte, sobre todo los posibles efectos —tan debatidos— de las redes informáticas y las telecomunicaciones. Algunos tipos de trabajadores podrían sustituir. en parte o en su totalidad, los desplazamientos diarios entre domicilio y trabajo por el llamado "teletrabajo", ya sea en el propio domicilio o en "oficinas de teletrabajo" situadas cerca de el.



4. Petrol consumption in transport in the UK, 1987.

4. Consumo de gasolina para fines de transporte en el Reino Unido, 1987.

and taxis. Air travel also accounts for a significant fraction, disproportionate to the passenger miles travelled by air. Air travel is the fastest growing transport sector in Britain. Rail travel accounts only for a minute fraction, 2% of petrol use although rail also of course uses electricity.

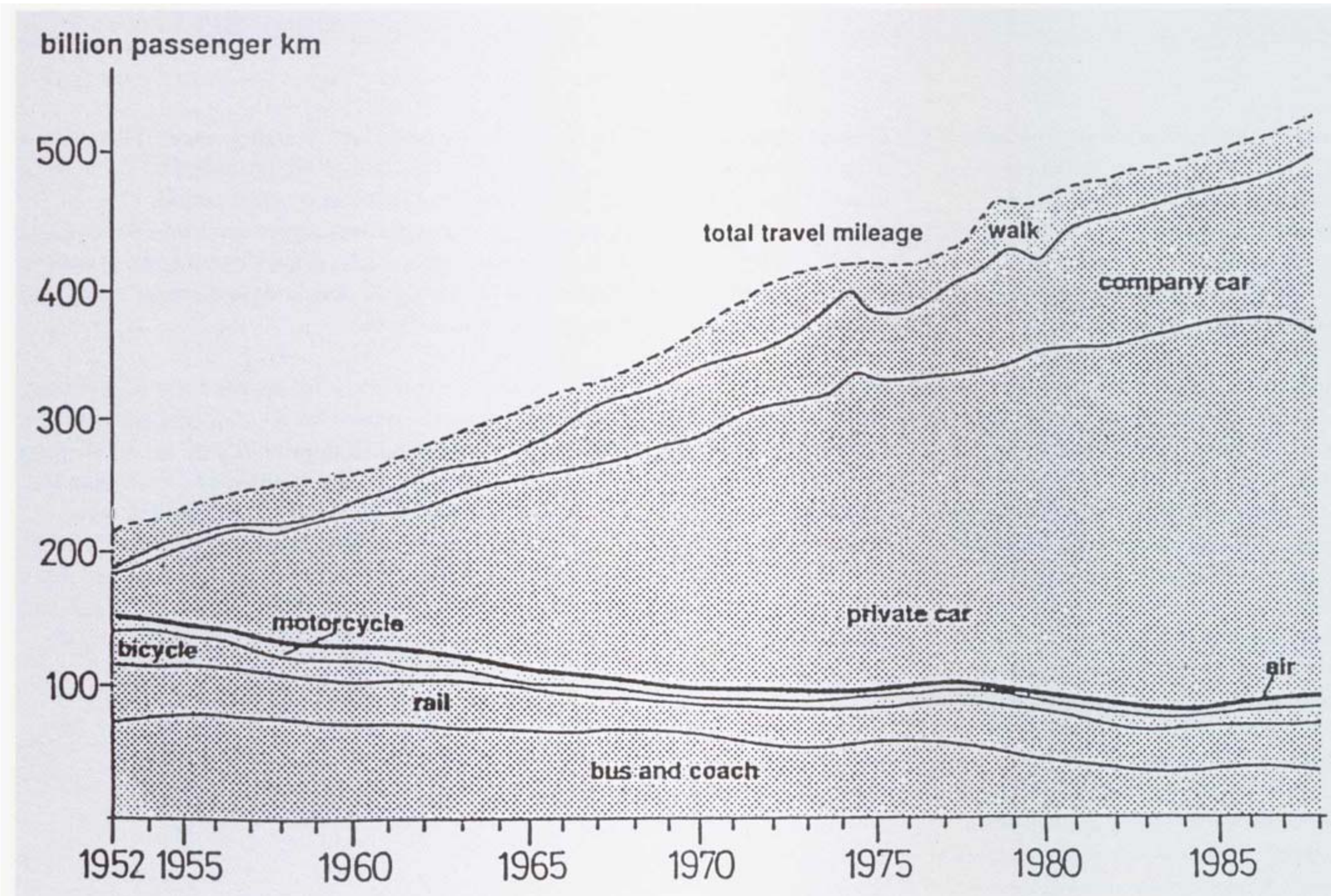
This table (5) shows the use of all fuels in transport in Britain in 1988, and the associated emissions of carbon dioxide. The total emissions from transport amount to some 130 million tonnes. Of this about 80% is accounted for by road travel, 2% rail, 3% water t'avel and 16% air travel. Taking all modes together, transport's share of national energy use in Britain has increased consistently since the 1950s, and grew particularly fast in the 1980s, when industrial energy use declined in proportion.

This growth in energy use in transport is brought about primarily by increases in the average distances travelled by people on a daily or weekly basis. This graph (6) shows total distances travelled by the British population, in billions of passenger kilometres, from 1952 to 1987. The growth in car use is very remarkable —it reflects of courses a massive increase in car ownership— having multiplied nearly tenfold in thirty-five years. See also the decline in cycle use; and the decline in the use of public transport, especially bus travel. (Even in the mid-1950s, total

	Fuel (PJ)	CO_2 (MT)	CO_2(%)
Rail:			
Gas/diesel	31	2.1	2
Electricity	12	2.5	1
Road:	1516	101.5	80
Water:	49	3.3	3
Air:	293	19.7	16
All modes:	1912	129.1	100

5. Fuel use in transport, and resulting emissions of CO', in the United Kingtom, 1988.
6. The growth of travel mileage, I952-1987.
Sources: transport Statistic Great Britain, 1976-1986
1978/79 National Travel Survey
LATA, 1985.

5. Consumo de combustible para fines de transporte y emisiones resultantes de CO' en el Reino Unido, 1988.
6. Aumento de las distancias recorridas, 1952-1987.
Fuentes: Estadísticas sobre el transporte de Gran Bretaña, 1976-1986.
Encuesta Nacional sobre Transporte 1978/79
LATA, 1985.



		No of persons carried	Energy used (MJ) per passenger mile	Energy used (MJ) per passsenger mile - if fully laden
Petrol car:	under 1.4 litre	1.5	2.79	1.05
	1.4 - 2.0 litre	1.5	3.21	1.20
	over 2.0 litre	1.5	4.96	1.86
Diesel car:	under 1.4 litre	1.5	2.42	0.91
	1.4 - 2.0 litre	1.5	2.96	1.11
	over 2.0 litre	1.5	3.93	1.47
Rail:	InterCity (100mph electric)	338 (60% full)	0.77	0.46
	InterCity 225 (125mph electric)	289 (60% full)	1.04	0.62
	InterCity 125 (125 mph diesel)	294 (60% full)	0.95	0.57
	Super Sprinter diesel	88 (60% full)	0.89	0.53
	Electric suburban	180 (60% full)	0.70	0.42
Double-decker bus		25 (33% full)	0.83	0.28
Single-decker bus		16 (33% full)	1.40	0.47
Minibus		10 (50% full)	1.15	0.57
Express coach		30 (65% full)	0.61	0.40
Air (Boeing 737)		100 (60% full)	3.90	2.34
Motorcycle		1.2	3.13	1.88
Moped		1	1.31	1.31
Bicycle		1	0.10	0.10
Walk		(1 person)	0.25	0.25

La tasa de renovación del parque móvil nacional es bastante alta, razón por la cual las mejoras en cl diseño pueden introducirse rápidamente, mucho más deprisa que en la infraestructura de los sistemas vial y ferroviario y en las edificaciones, que tan sólo experimentan cambios significativos a lo largo de décadas.

Analizando la cuestión desde una perspectiva más bien simple. podemos afirmar que si lo que se pretende es conservar los niveles de acceso de la población a los lugares de trabajo, de compras o de ocio, reduciendo al mismo tiempo las distancias que tienen que recorrerse, eso sólo puede conseguirse replanteando la explotación del suelo. O bien se aumenta la *(lr'ach/ad* de las asen-

tamientos, o bien se modifica la mezcla de usos del suelo para que las viviendas. los trabajos y los servicios queden situados más cerca unos de otros y no se vean segregados en diferentes zonas de nuestros pueblos y ciudades.

Esta idea de la conveniencia de usos mixtos o densidades mayores (o ambas cosas) es algo cn lo que han-insistido algunos autores de trabajos recientes sobre transporte, planificación y energía. En Gran Bretaña ha surgido un gran entusiasmo por lo que se conoce corno "ciudad

distances travelled by car and by public transport were roughly equal). This pattern of increasing car use is both caused by, and a cause *of,* the processes of decentralisation which have been going on in England over the period: decentralisation on a regional scale, from London out across the whole South-East of the country: and decentralisation at an urban scale, of residential areas to the suburbs and villages, employment to 'office parks' and 'industrial parks'. shopping to out-of-town centres and suburban supermarkets.

Another cause of growth in energy use in transport is this transfer of modes, from bus to the private car. This chart (7) compares typical levels of energy use per passenger kilometre by different transport modes. Naturally in vehicles which carry more than one person the figures are crucially affected by the *load* factor –that is, what proportion of seats in the vehicle are actually occupied. The figures in the centre column take some average assumptions for load factors. The column on the right is for vehicles which are fully laden. See how there is typically a difference of a factor of three or four between private cars (or motorcycles) on the one hand, and rail or bus on the other. Air travel is very energy-intensive, as you would expect,

7. Primary energy requirements of travel modes.

7. Requisitos básicos de energía de los medios de transporte.

compacta" y el gobierno ha publicado recientemente una serie de directrices dirigidas a los planificadores que recomiendan la concentración del nuevo desarrollo urbanístico en los centros de las poblaciones actuales.

Como ha señalado Peter Hall. existe aquí una especie de círculo vicioso. Al aumentar el número de personas que tienen acceso a un vehículo, la explotación del suelo tiende a diversificarse cada vez más. Eso dificulta el desplazamiento en transporte público, en bicicleta o a pie y hace que sea mayor el número de personas obligadas a utilizar sus coches.

En una ciudad existen distintas posibilidades sobre exactamente *dónde y con que configuración detallada* podría concentrarse el nuevo desarrollo urbanístico y cambiarse las densidades.

Empezamos, por tanto, con el análisis empírico de una gran zona situada en la región centro este de Inglaterra. Utilizamos mapas de explotación del suelo para determinar la distribución de parcelas dedicadas a diferentes actividades. Utilizamos mapas de carreteras para medir las características geométricas y topológicas del sistema vial. Basándonos en esas mediciones empíricas, elaboramos una configuración regional urbana ideal o arquetípica de explotación del suelo y de las carreteras, que comparte muchas de las características observadas en la configuración actual, pero de la que se han eliminado los efectos de los accidentes de la topografía y la historia local (13).

Con todo. no existe necesariamente una correlación entre la densidad del desarrollo y la concentración o dispersión de ese desarrollo según diferentes configuraciones espaciales. Como ha indicado Lionel March en una importante serie de estudios geométricos de la explotación del suelo: "Es tan posible tener una configuración dispersa de alta densidad como una configuración concentrada de baja densidad°.

Las Opciones 2 y 4 fueron diseñadas para probar lo que parecían ser características prometedoras desde el punto de vista de la conservación de la energía.

although not more so than luxury cars carrying only their drivers. The difference between the two columns for energy per passenger-kilometre indicate the potential for energy saving through increased load factors, especially in private modes —by car sharing or car pooling for example. Most energy-efficient of all modes are walking and cycling —cycling using typically one-thirtieth of the energy expended per passenger-mile in cars.

There are engineering improvements which can be made to vehicles themselves of course, to improve the efficiency with which they use fuel. These include not just improvements to engine design, but also to the transmission, to body design (to reduce weight and lower air resistance) and to tyres (to reduce rolling resistance). One recent review foresees production cars with petrol or diesel engines in the fairly near future which might have fuel consumption rates, under average drying conditions, of around 25 kilometres per litre. Another possibility is a move away from the internal combustion engine towards electrical propulsion for cars. At present, however, battery technology is not sufficiently advanced to provide the performance and range of petrol-driven cars. Also electric vehicles may make less contribution to local air pollution as they move; but if the electricity used to charge their batteries is generated in power stations burning fossil fuels, then the larger problems of pollution and CO_2 emissions are merely displaced elsewhere.

Suppose, however, we set on one side those reductions in fuel use and the resulting cuts in emissions which can be achieved by improvements in the mechanical performance of vehicles. (There are also savings which could be achieved by imposing speed limits. and promoting better driving habits, since fuel consumption increases steeply at higher speeds.) It is clear that further reductions in overall fuel use in transport could be made in principle in two main ways:

1) By cutting the total distances travelled, and

2) by shifting trips from more energy-intensive to less energy-intensive modes: principally from car to public transport, over long distances from air travel to train, and best of all from mechanical modes to cycle or walking.

My colleague Mark Barrett and I have made some experiments, to look at the potential here, using a simple computer model of the passenger transport system in Britain. The model is called PASS. The idea of these experiments is to look at a national level, at change in journey lengths and in the proportions of trips made by different modes, to see what effects these have on energy use and CO_2 emissions. These are purely hypothetical changes, and leave to one side all questions of how they might actually be achieved through political or economic policy. I will come back to policy issues later.

PASS uses data from the British National Travel Survey on total distances travelled and numbers of trips. These are broken down into 15 travel purposes, 14 distance bands and 25 modes. The sample figures from the survey are grossed up for the whole of the UK. A chain of calculations is then made which relates the variables shown in this figure (8):

1) Journey frequency by distance (% of all journeys)

2) Total distance (passenger kilometres)

3) Modal split (% distance by mode)

4) Modal distance (passenger kilometres)

5) Vehicle load factor

6) Vehicle distance (vehicle kilometres)

7) Vehicle specific fuel consumpftion (MJ/km)

8) Vehicle fuel consumption (PJ)

9) Carbon dioxide emission (Mt)

9. Result of experiments with PASS model.

9. Resultado de los experimentos con el modelo PASS.

Por el contrario. la Opción 3 concentra la población desplazada en una configuración espacial formada por ocho nuevas pequeñas ciudades satélite en lugares de confluencia de carreteras principales. La Opción 5 propone la dispersión de la población desplazada en veinticuatro pueblos. ya sean nuevos o expandidos.

Seguidamente analizamos esas diferentes configuraciones utilizando el modelo. El consumo de combustible para fines de transporte se calculó para los vehículos de transporte público por un lado, y para los automóviles particulares por otro. en función de las características técnicas medias de los vehículos británicos típicos.

Las eficiencias de combustible varían dependiendo de la velocidad media, según calculó el modelo para cada conexión en el sistema vial, y dependiendo de la capacidad y la congestión de las carreteras. Los niveles estimados de consumo de energía se determinaron en todos los casos frente a los niveles de accesibilidad de la población a los lugares de trabajo y los servicios. Los resultados fueron. en su mayoría. negativos. No se observaron variaciones significativas en el consumo de combustible entre las cinco configuraciones, ni en el transporte ni en la calefacción de las viviendas.

Nuestros experimentos parten del supuesto de que no se producirán grandes cambios en la prestación de servicios de transporte público, salvo una mejora de los servicios de autobús. Si se realizaran grandes inversiones para mejorar la calidad, la frecuencia y el atractivo económico general del transporte público, la capacidad de conservación de energía de algunas de nuestras pautas del explotación del suelo podría ser mayor de lo que han sugerido nuestros experimentos por el momento.

El clima político público ante los problemas del tráfico ha cambiado de forma muy pronunciada en Gran Bretaña en los últimos dos o tres años, y alternativas que hace relativamente poco tiempo habrían sido impensables, como la prohibición completa de que circulen coches por determina-

1) Changes in trip lengths

Ave trip length (km)	*Passenger.km x 10^9*	*Passenger.km by car (%)*	*CO_2 (Mt)*
6.4	644	77	76
6.0	595	71	71
5.5	547	70	65
5.0	499	70	59
4.5	450	69	53
4.0	402	68	48

2) Changes of transport mode

(Average trip length remains constant at 6.4 km)

Mode shift (%)	*Passenger.km x 10^9*	*Passenger.km by car (%)*	*CO_2 (Mt)*
0	644	77	76
20	644	65	70
40	644	52	64
60	644	40	58
80	644	28	52
100	644	15	45

Values for load factors and fuel consumption of vehicles are taken as typical of the current situation. Load factors are assumed to vary by trip purpose: thus private cars have lower load factors for work trips than for shopping and social uses.

The first experiment involves the assumption that trip lengths become generally shorter. In the PASS model this is simulated by shifting different percentages of trips to the next shortest distance band. This table (9) shows how both the average stage length and the total distance travelled are progressively reduced as the percentage of trips shifted in this way increases. As trips are shifted to the very shortest stance bands there is some effect on modal split, as car trips are transferred to other modes such as cycling and walking. However, this effect is small, and in general fuel use and carbon dioxide emissions are nearly linearly related to the total distance travelled. Thus a 40% reduction in total passenger-kilometres (back to the position of about 1970 in Britain) results in a 40% reduction in emissions.

The second experiment relates to modal split. In the PASS model different percentages of trips are shifted from cars to walking, cycling or trains, up to certain assumed maximum shifts for each distance band. The results of the experiment are das zonas o la interrupción del programa nacional de construcción de carreteras, están siendo objeto de debate hoy en día.

Consideraremos toda una serie de políticas para mantener sin cambios las densidades y las mezclas de usos del suelo, introducir innovaciones en el transporte, como la restricción del uso y el aparcamiento de los automóviles, y adoptar algunas tecnologías nuevas en el transporte público.

shown in this table (9 again). Average stage length and total distance travelled now remain the same, but the distance travelled by car drops as increasing proportions of the maximum assumed modal shift are put into effect. At the extreme, only 15% of passenger-kilometres are by car, and carbon dioxide emissions are reduced by about 40%.

If the two experiments, on stage length and modal shift, are put together, then the combined effects of the maximum changes considered in each case result in a reduction of 50% in carbon dioxide emissions.

Now these hypothetical experiments with PASS represent extremely large changes in the pattern of passenger transport in Britain. Nevertheless they give some notion of the scale of transformation necessary if the targets being discussed for cuts in CU emissions, say by the middle of next century, are actually to be achieved They raise the question of what sorts of policies —financial, social, planning or transport policies— might possibly be devised to bring about such major changes?

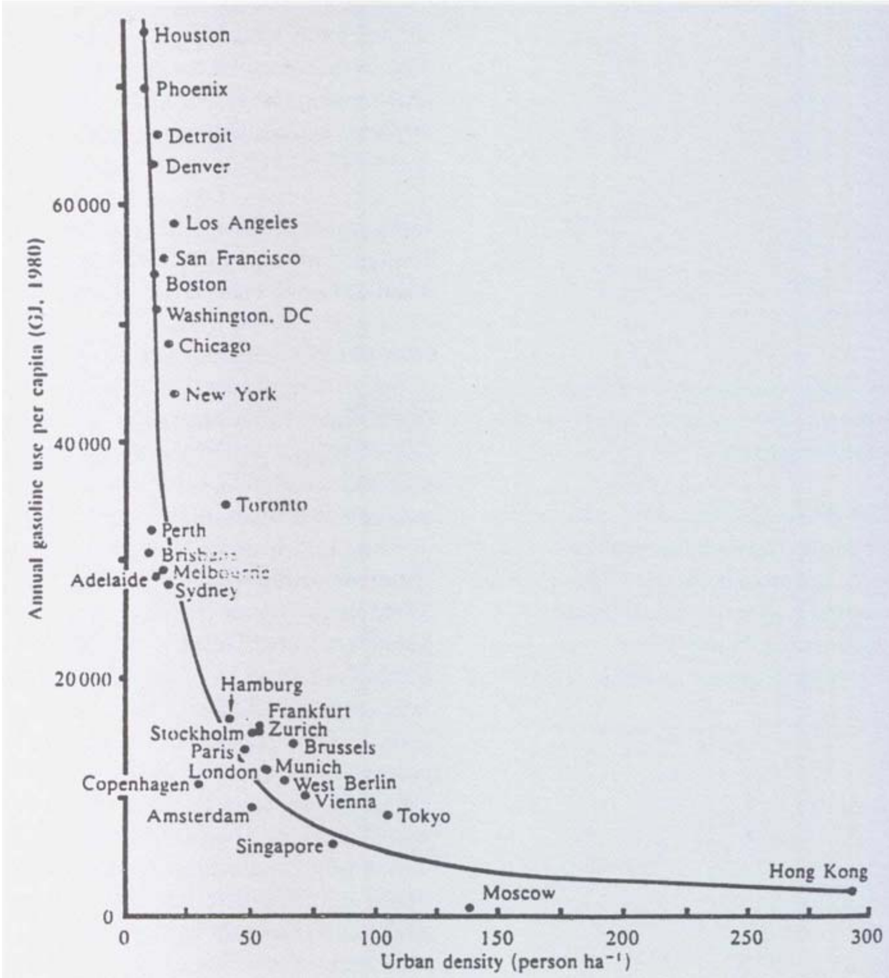
There are certain kinds of development in patterns of work, shopping and education which *might* arguably reduce fuel use in transport: notably the much-discussed possible effects of telecommunications and computer networking. Some or all commuting travel by certain types of workers might be substituted by so-called 'teleworking', whether at home or in local neighbourhood 'teleworking offices'. Some shopping. especially of a routine nature, might be done remotely by computer or video terminal, as is done to an extent already in France and the United States. Some banking and reservation services operate in this way already in many countries. The likelihood of such trends going further, on what scale, and with what other social and economic consequences —all these are matters about which it is difficult to make quantitative predictions. I am not going to try to make any myself. Nevertheless they do seem to offer some promising ways for reducing passenger travel, without sacrificing the benefits of decentralisation and dispersal of land uses.

I have already talked about mechanical improvements in vehicles and other measures such as higher vehicle taxes, fuel taxes, speed limits and so on. These have the attraction of being measures which are easier than others to implement in the relatively short tern —although their social and economic effects may be far-reaching and socially quite unjust. The rate of turnover in the national stock of vehicles is relatively fast. and design improvements can therefore be introduced quickly—much more quickly than in the infrastructure of road and rail networks, and in the building stock, which only change significantly over decades. Nevertheless there do appear to be ways in which configurations of transport networks and distributions of land use can in themselves have significant effects on fuel use in transport. It is these which I would like to talk about in the remainder of my lecture.

Looking at the question in a rather simple-minded way, we can say that if people's levels of access to places of work. places to shop or places of entertainment are to be preserved, and at the sane time the distances which people travel are to be reduced, then this can only be achieved by rearranging land uses. Either the *density* of settlements must be increased: or the mixture of land uses must change so that

10. Petrol use per capita versus urban population density
(source: Newman and Kenworthy. 1959).

10. Consumo per capita dc gasolina frente a densidad de población urbana
(fuente: Newman and Kenworthy. 1959).



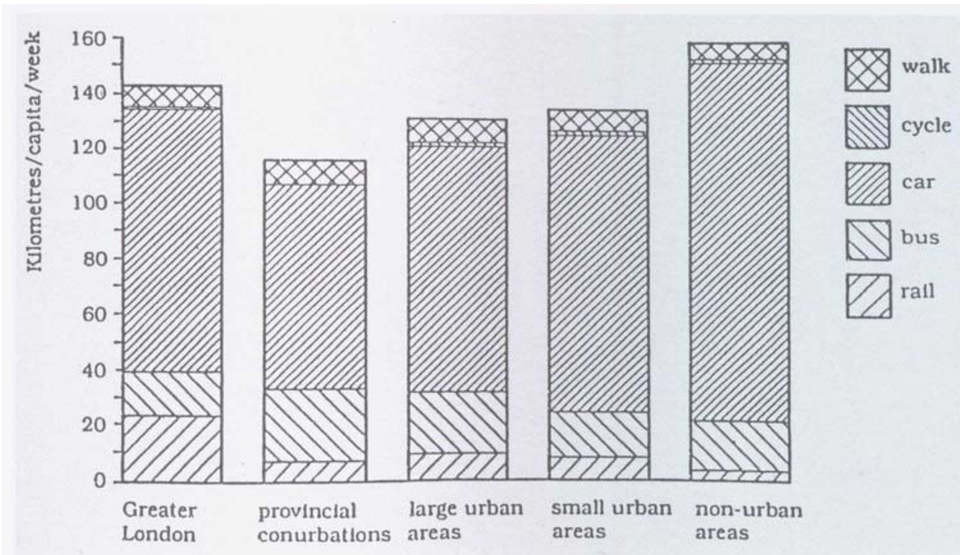
houses, jobs and services are located close together and not segregated in different parts of our towns and cities. This idea of the desirability of mixed uses, or higher densities (or both) is something which has been reiterated by a number of recent writers on transport, planning and energy. In Britain it has found expression in enthusiasm for the so-called 'compact city', and in recent government guidance to planners, urging them to concentrate new development into the centres of existing towns. In the United States the same themes are to he found in the 'new urbanism' of architects such as Peter Calthorpe.

Empirical evidence from existing cities certainly seems to support the proposition that increasing densities will be effective in reducing travel distances. This is a graph (10) from the very influential and much-discussed work of Newman and Kenworthy in which average urban population densities are plotted against annual use of gasoline per person, for some thirty large cities worldwide. This demonstrates a very clear overall relationship: the lower the average density of the city. the greater the petrol use per capita. Very high density cities like Singapore and Hong Kong lie down to the bottom right, and very low density North American cities are up at top left. There has been some controversy about how, precisely, these results should be interpreted. It has been pointed out that those cities where fuel use is higher (mostly in the United States) are in many cases also those where petrol prices are lower, incomes and so levels of car ownership are higher, and vehicles are less efficient.

On the other hand there are strong *a priori* reasons for believing low density in itself to be associated both with longer average journeys, and with preferential use of cars over public transport. As Peter Hall has pointed out, there is a kind of vicious circle here. As more people have access to cars, so land uses tend to become more spread out. This in turn makes public transport, cycling or walking less feasible, and forces more people into their cars.

Other studies have confirmed this association of increased travel distances, and increased car use, with lower densities. This figure (11) reproduces some statistics for Britain. which are now more than twenty years old, but are still suggestive of differences which have probably since become even more marked. The statistics compare total distances travelled per person per week by different modes in settlements of different sizes in Britain: in rural areas, in 'small' and 'large' urban areas, in provincial conurbations (Birmingham, Manchester, Liverpool and Glasgow) and within Greater London.

Ignoring London for the moment: there is a clear trend here, from the smallest villages to the largest conurbations, in the average distances travelled, which decrease as settlement size increases. There is little variation in the *numbers* of trips per person here: the difference is almost wholly attributable to trip lengths. The average distance travelled by car in the rural areas is nearly twice that of the provincial conurbations.



11. Distance travelled by size of settlement.

11. Distancia recorrida según el tamaño del asentamiento.

At the same time there is a clear *increase* in the distances travelled by public transport —train and bus— as settlement size increases, which continues to apply to the extreme case of London.

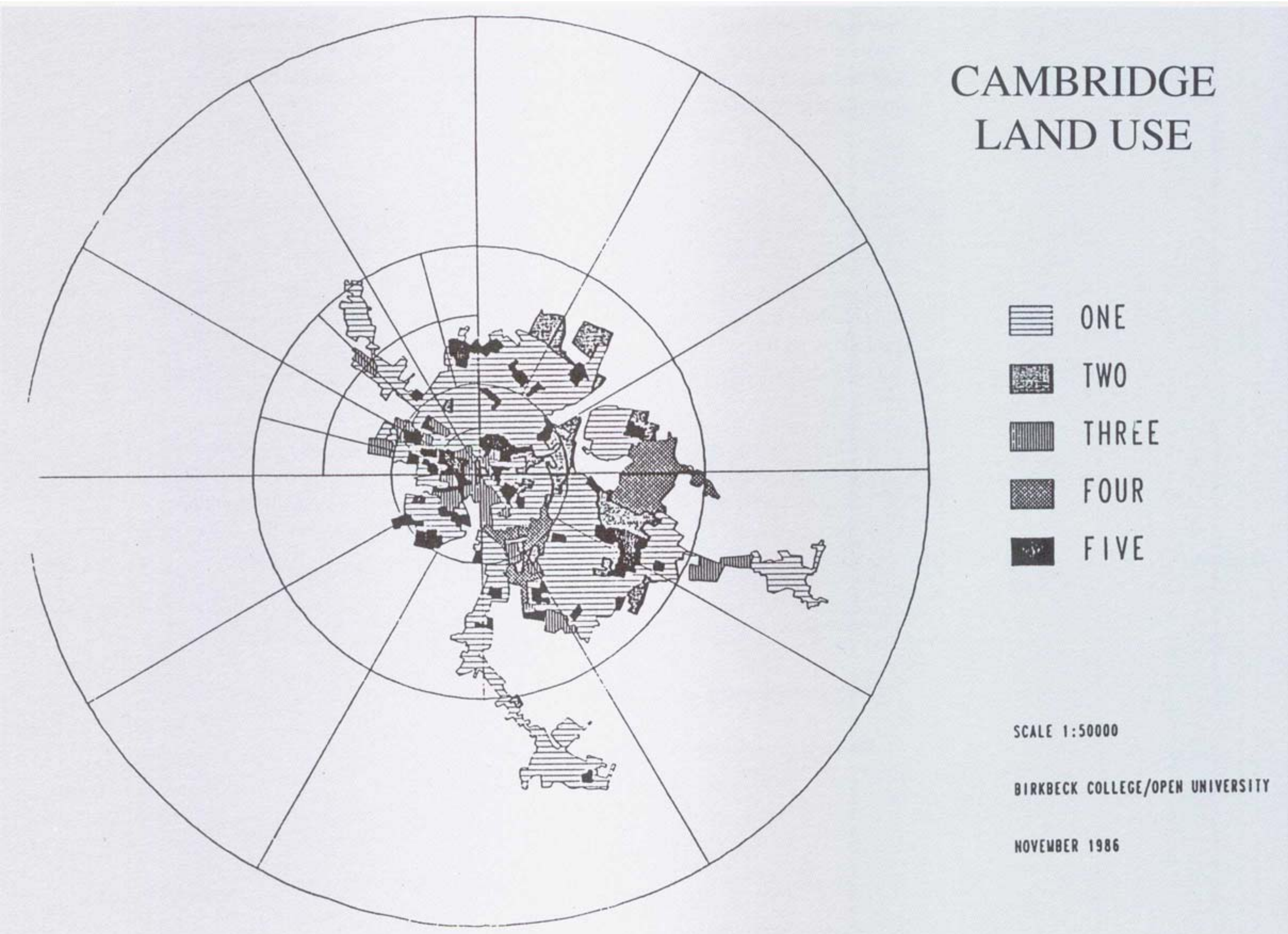
Once again there are likely to be many factors at work here which serve to complicate any supposed simple relationship of settlement size to travel patterns. But it is difficult to escape the conclusions, all the same, that the concentration of development at higher densities results in shorter car journeys (except perhaps in London): and that the larger the city size, the higher the proportion of all travel tamed by the public transport system.

We have looked so far at the question of travel *distances* as they are affected by density, and by the *size of* settlements. But these are very gross measures of the overall properties of whole towns or cities. Within one city and its hinterland there are further possibilities, as to precisely *where,* and *in what detailed pattern* new development might be concentrated, and densities changed.

Over the last ten years my colleagues Peter Rickaby and Tomas de la Barra and I have been studying some of these relationships between energy efficiency, land use patterns and the structure of transport networks. These have been theoretical investigations, rather than the kinds of empirical analyses of actual settlements which I have been showing you so far. We have chosen to look first at the regional scale: more recently at the urban scale. Because of the complexity of the systems

12. Cambridge Land Use.

12. Uso del suelo, Cambrige.



involved, and the interactions between various conservation options, we have been using a land use and transport simulation model called TRANUS which has been specially adapted to calculate energy use, both in buildings and in vehicles. TRANUS has been developed by de la Barra and colleagues in the consulting firm Modelistica, based in Caracas in Venezuela.
Because of the inertia and slow rate of change in settlement patterns, we thought it best to start from the existing distribution of land uses and the existing transport network in a representative region of Britain; and then to make modifications which could reasonably by achieved by the application of planning policies over an assumed twenty-five year period.

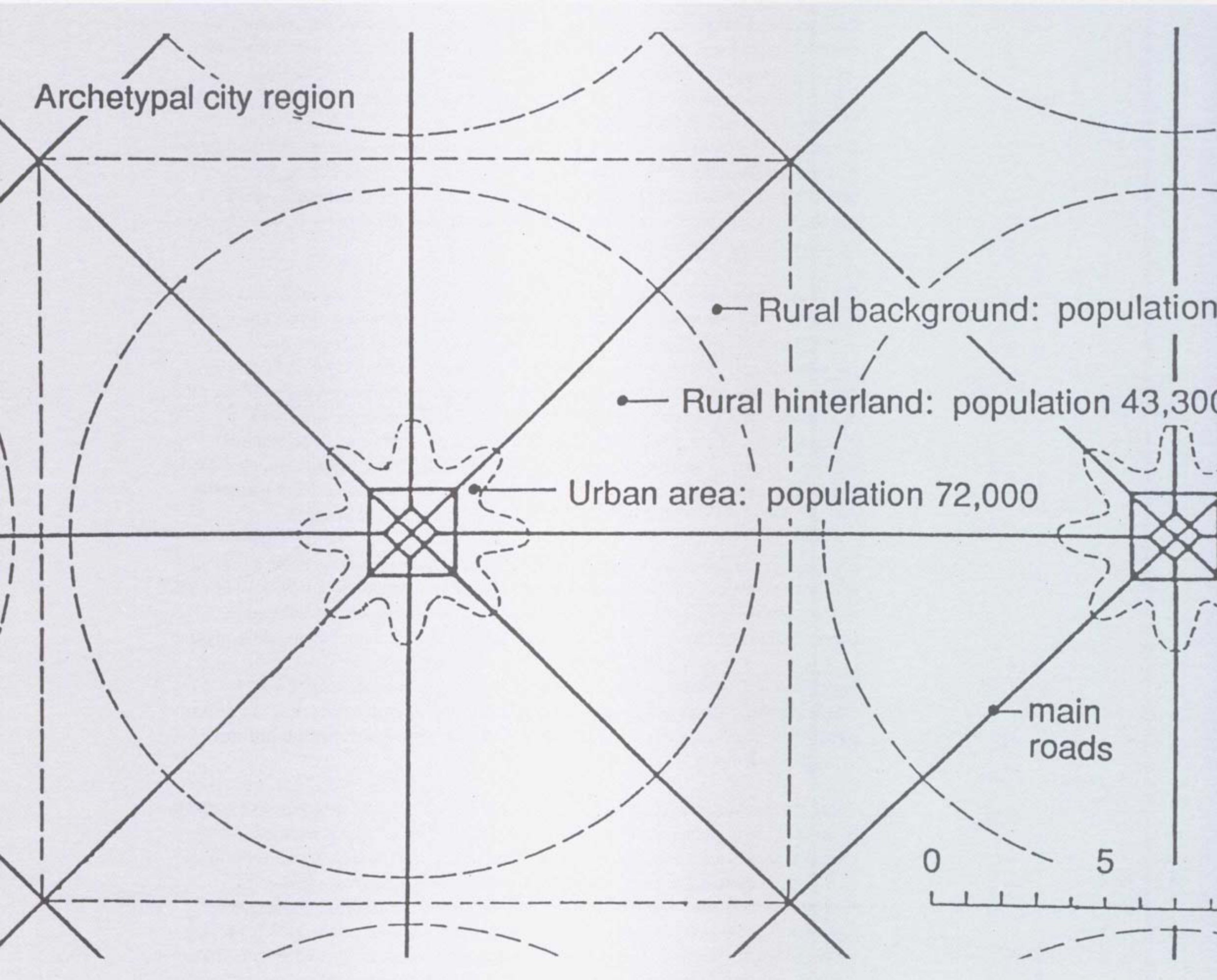
We began therefore with an empirical analysis of a large area of central and eastern England. Land use maps were used to determine the distribution of parcels of land devoted to different activities (12). Road maps were used to measure the geometrical and topological characteristics of the road network. On the basis of these empirical measurements an idealised or archetypal city-regional configuration of land uses and roads was developed, which shares many of the observed characteristics of the actual pattern, but from which the effects of accidents of topography and local history have been removed (13). The average lengths of road links, numbers of roads meeting at junctions and numbers of road links bounding each enclosed area of land are all representative of the real network.

The changes of this pattern which were studied for their impact on energy use, all involved relocating 25,000 people from the rural hinterland, along with some or all of their associated places of employment and services, within five alternative configurations of land uses (14). The road network was left unchanged throughout.

In option I the relocated population was all concentrated in the central city, reflecting the `compact city' kind of argument that higher densities, and the closer integration of residences with workplaces and services, would result in shorter average trip lengths.

There is however no necessary correlation between density of development and the concentration or dispersal of that development in different spatial patterns. As Lionel March has pointed out in an important series of geometrical studies of land use: "It is as possible to have a high density dispersed pattern as a low density concentrated pattern". Options 2 and 4 were designed to test what seemed to be promising features, from an energy conservation standpoint, of March's proposals for high-density linear developments, or going back to earlier precedents, the linear cities of Soria y Mata and the Russian `disurbanists'. In option 2 these high density corridors follow the main arterial roads. In option 4 the main roads are left free for through-traffic, and the ribbon development is run along the secondary roads.

It was thought that linear developments of these types might be specially conducive to an increased use of public transport, since the concentration of population onto a small number of routes might allow fast, frequent services, so encouraging a transfer from private cars.

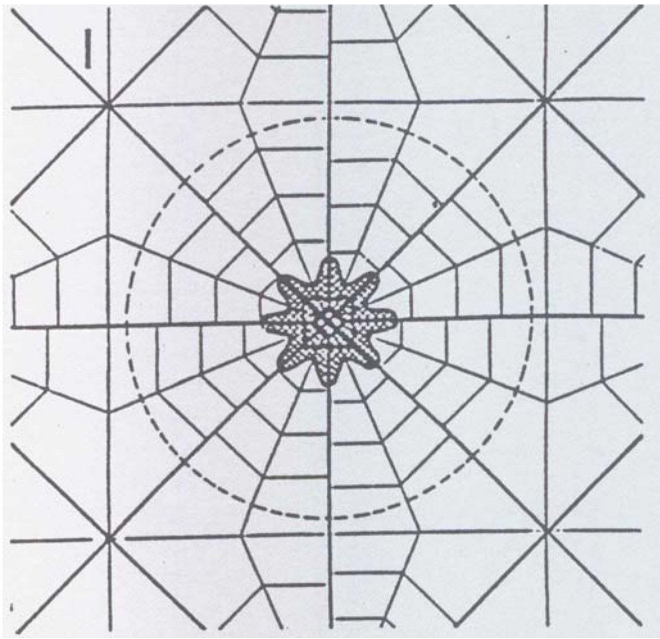


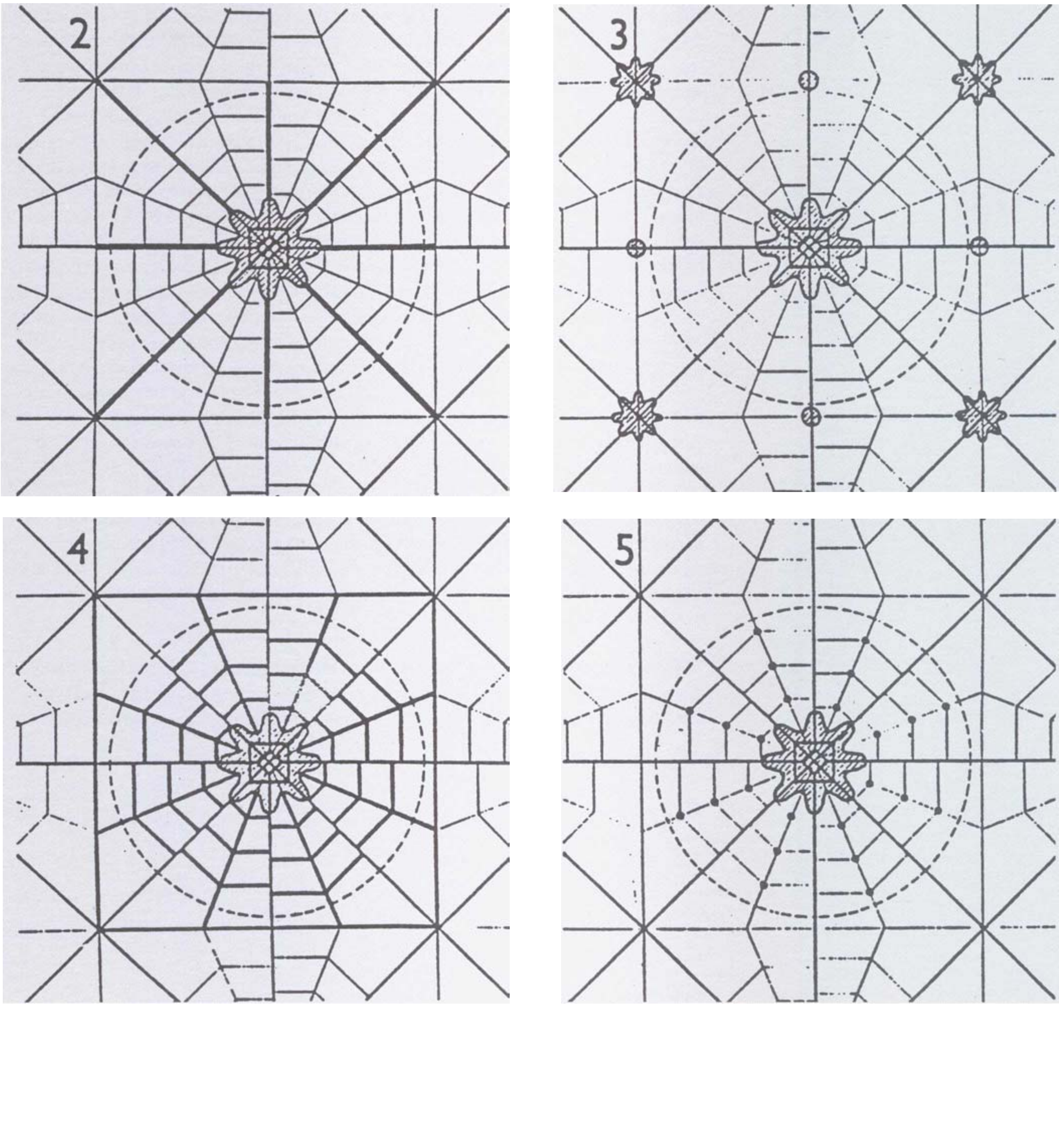
13. Archetypal city region.

13. Región urbana arqutípica.

14. Five alternative city-regional configurations.

14. Cinco configuraciones distintas de regiones urbanas.





Option 3, by contrast, concentrates the displaced population into a pattern of eight small new satellite towns at junctions of the major road system. It has some affinities with the `federation of garden cities' envisaged by Ebenezer Howard, the father of the British garden city movement —although Howard's satellites were linked by rail not road. Option 5 involves dispersing the displaced population into twenty-four villages, either new or expanded. These different patterns were then evaluated using the model. Fuel consumption in transport was calculated separately for public transport vehicles and private cars, on the basis of average performance characteristics for typical British vehicles. The fuel efficiencies vary with average speed, as calculated by the model for each link in the road network, and depending on road capacity and congestion. The estimated levels of energy use were set, in each case: against the levels of accessibility obtained by the population to places of work and services.

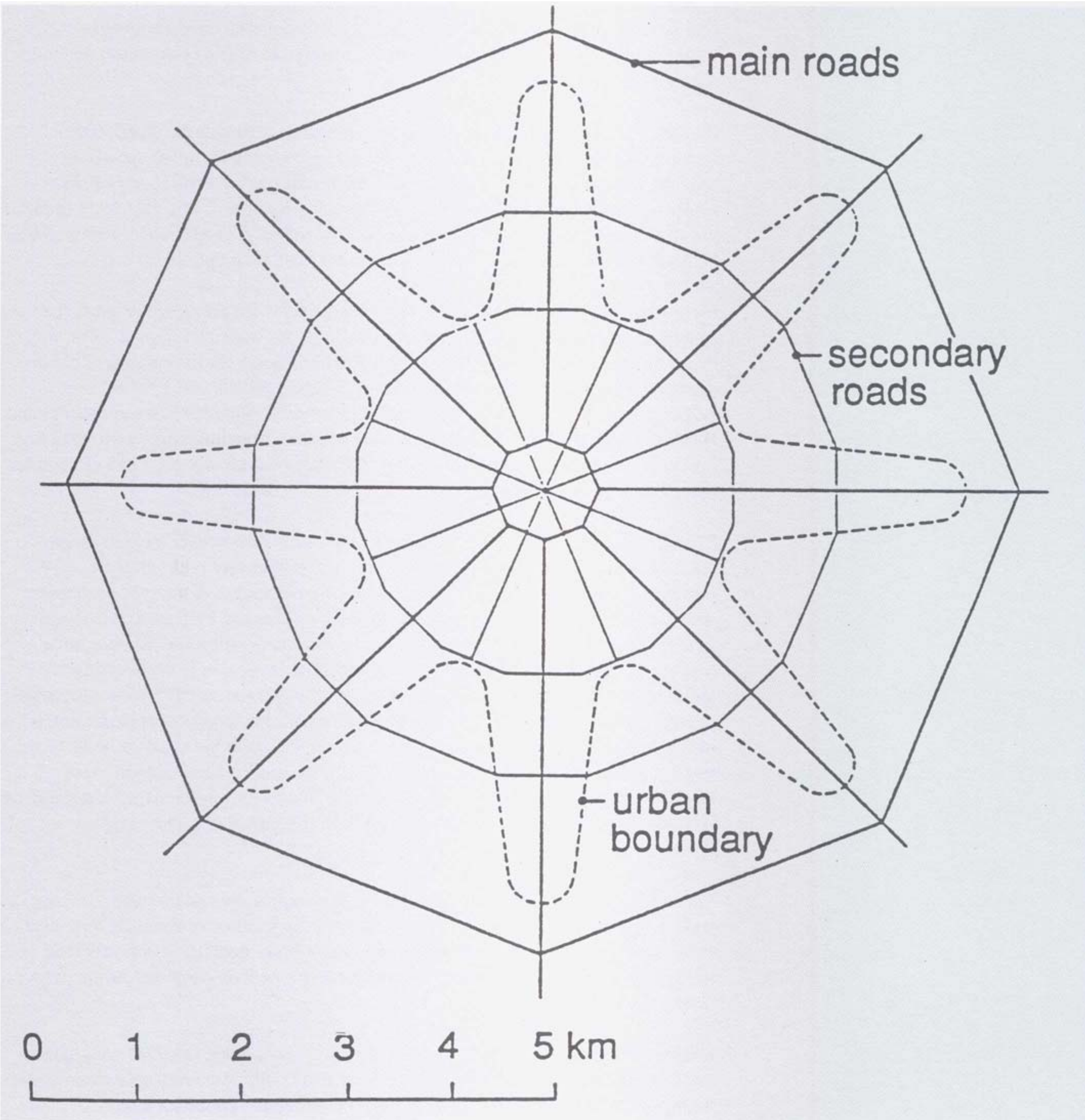
The six regional patterns —one existing and five hypothetical— were compared against three national scenanos of future economic and energy-supply conditions in Britain: a high growth `business as usual' scenario, a medium growth `technical fix' scenario, and a low or no growth `conservation' scenario.

Comparing the existing pattern with the five new arrangements, in all cases overall energy use varied substantially, as would be expected, between the three scenarios, `high', `medium' and `low'. It fell by 29% going from the `high' to the `medium' scenario, and by 48% going from the `high' to the `low' scenario. In all scenarios less energy was used overall in all the hypothetical configurations than in the existing pattern, and the rank order of the new patterns in this respect did not change between scenarios. However these fuel savings were achieved in every case at the expense of reduced accessibilities or increased costs, relative to the existing situation; suggesting that the evolved historical pattern of land uses and transport routes is actually rather `efficient' in balancing accessibility and travel cost.

On the other hand two new patterns —option 1, the concentrated central city, and option 5, the village dispersal scheme— showed significant savings in transport fuel use ranging between 9% and 14% for option 1, depending on the scenario, with rather smaller savings in option 5. In both cases it appears that, by concentrating the previously scattered population of the rural hinterland, average journey lengths both to work and services have been shortened. This result is in broad agreement with the findings of a number of other studies, which have found reductions in energy use in transport produced by concentrating new development in small to medium-sized clusters.

Option 3, the pattern of satellite towns, is not however successful in reducing average journey lengths. This is because the rural population has been moved *outwards* to the periphery of the region; and although some jobs and services are relocated to the small new towns, there is still extensive commuting from these towns to the central city.

The advantages which it was imagined that the two patterns of high density linear development, options 2 and 4, might have for encouraging public transport were not born out by the analysis. The public transport in question was assumed to



15. Archetypal town form, based on 20 real towns of around 100,000 population.

15. Configuración urbana arquetípica, basada en 20 poblaciones reales de unos 100.000 habitantes

consist of bus services, but without special bus lanes. The concentration of car journeys along the main routes in option 2 resulted in traffic congestion, which in turn slowed the buses.

It seems at least possible that these results might be different for other public transport technologies, such as light rail or tram, running at higher speeds on separate tracks. Light rail might be suitable too for linking central and satellite towns in opcion 3 —as in Howard's `garden city federation'. The TRANUS model is capable of representing the characteristics of these types of system; and it would be good to make some new experiments to evaluate such options.

Meanwhile we have been carrying out other work, at the urban scale, using the same analytical tools and a similar methodology. As with the regional work, the research work, the research started from empirical analysis, in this case of twenty provincial English towns with populations between 50.000 and 150.000. An archetypal town form has been derived whose overall shape (15), as in the regional study, is an eight-armed `starfish' following the major radial roads, with inner and outer ring roads and a pattern of streets and blocks whose topology and dimensions correspond to characteristics of the twenty actual towns.

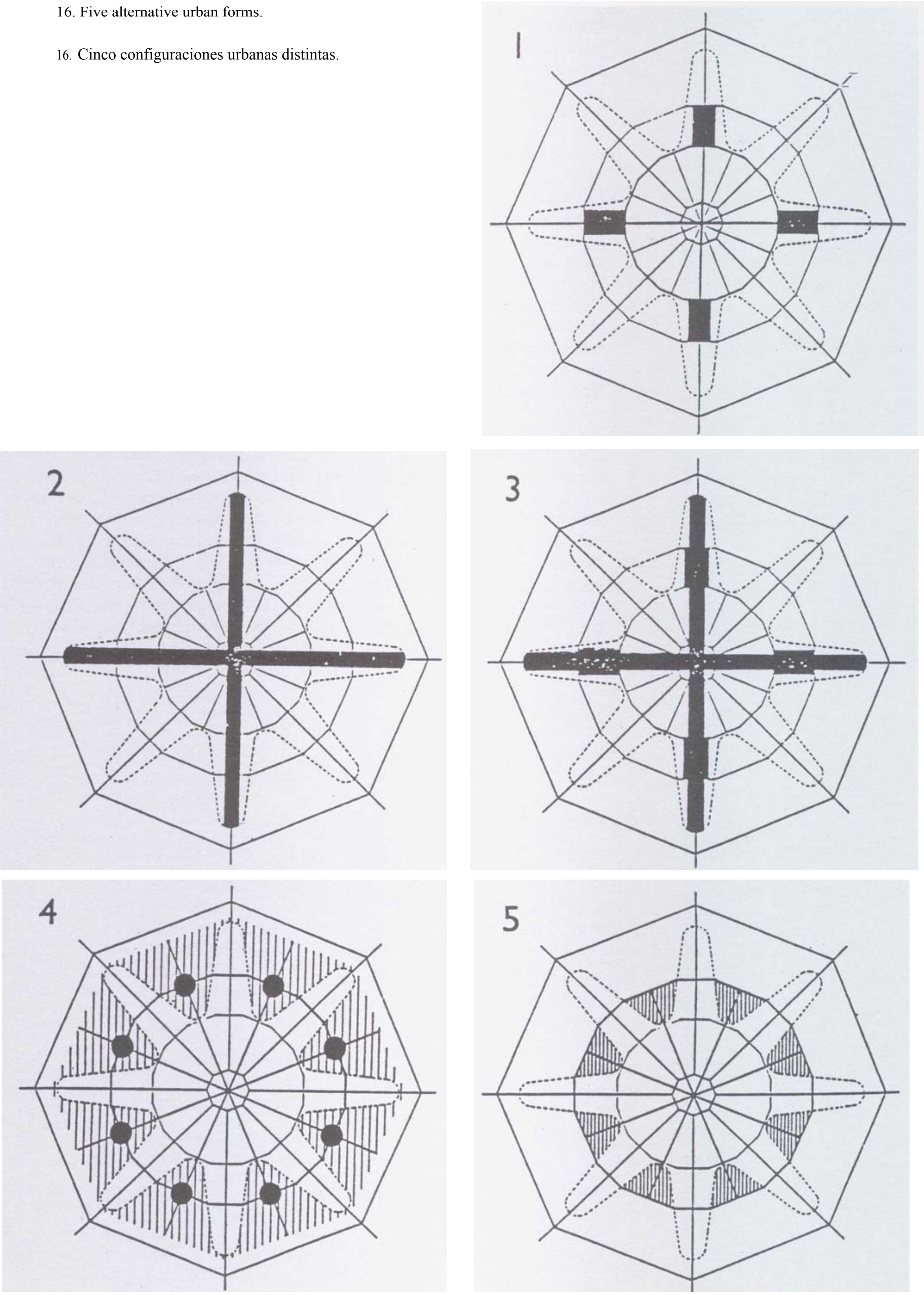
Five policies for planning and control of new development over a twenty-year period have been compared (16). These do not involve any net change in population, but assume a decrease in average household size, and a consequent increase in the number of households, number of jobs and total area of floorspace. In three of the options, new development is contained within the existing town boundary: either by building up existing sub-centres (option 1), channelling new building into high-density corridors along main roads (option 2), or a combination of both policies (option 3). The remaining two patterns assume that expansion takes place on the periphery of the town, either at low densities between the arms of the star but inside the outer ring road (option 4), as is indeed happening in many English towns; or else into smaller areas of high density (option 5), which might be suitable for the introduction of combined heat and power or district heating schemes.

The results were essentially negative ones. No significant variations in fuel use were found between the five patterns, either in transport or in domestic heating. (The possible independent savings for CHP or district heating in option 5 were not taken into account.) There was very little shift in travel mode in any of the patterns, from private car to bus.

It should be remembered that these are medium-sized cities (100.000 population), not metropolitan regions. They are quite compact, with relatively short journeys to work, and are only just beginning to experience serious problems of traffic congestion. In these circumstances it seems that improved bus services to the newly developed area fail to tempt drivers away from their cars. This contrasts with the savings in fuel use in passenger transport of up to 15% over a 25 year period which we saw in the experiments at the regional scale.

16. Five alternative urban forms.

16. Cinco configuraciones urbanas distintas.



On the other hand, the assumptions made in all our experiments, at both scales, were relatively conservative. They did not envisage large changes in lifestyle, nor for example abrupt rises in the real price of fuels. Indeed they were made using transport models embodying assumptions which are quite normative, and are in effect `tuned' to current high mobility, motorised, suburbanised societies.

If petrol prices were to be increased substantially, as by the application of the kind of `carbon taxes' which are being discussed, or if petrol were to be rationed, then perhaps quite other planning options might become feasible. Our experiments assumed no great changes in public transport provision, other than improved bus services. If heavy investments were to be made to improve the quality, frequency and general economic attractiveness of public transport, then again the energy consevation potential of some of our land use patterns might be greater than our experiments so far have suggested. The public political mood in relation to traffic problems has changed very markedly in Britain over the last two or three years, and options which would have been unthinkable quite recently —such as complete bans on car traffic in certain areas, and a halt to the national programme of road building— are now on the agenda.

We are just about to embark on a new programe of work, using the TRANUS model, which will take the English city of Swindon as a case study. Swindon has a population of 125,000. It expanded very rapidly during the 1980s and now has special problems posed by the fact that many commercial and industrial uses have migrated to the periphery of the town. We will be looking at a whole series of policies to do both with densities and mixes of land uses as before, and with transport innovations, including restrictions on car use and on car parking, and some new public transport technologies —or in truth some old technologies newly revived— such as light rail and tramways. We are hoping that these policies in combination will prove to be more effective than our earlier theoreticael experiments, in shortening journeys, changing modes and conserving fuels.