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LUCAS HEIGHTS RESEARCH LABORATORIES

GENERAL ASPECTS OF THE METEOROLOGY AND WIND FLOW PATTERNS AT THE NATIONAL MEDICAL CYCLOTRON SITE CAMPERDOWN, N.S.W., AUSTRALIA

by

G.H. CLARK,
F.J.K. BARTSCH

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ABSTRACT

As part of an assessment into the consequences of a potential accident at the National Medical Cyclotron, Camperdown, N.S.W., Australia, two meteorological stations were installed to monitor the winds, temperatures and atmospheric dispersion conditions. In spite of the relatively poor performance of the stations, the wind data indicated significant effects of local buildings and the general urban surface roughness features. The prevailing winds during the study were from the north-north-west at night and south-south-west or north-east sea breezes during the day. Atmospheric stability/dispersion categories were typical of an urban heat island location.

CONTENTS

1. INTRODUCTION

In response to a request from the Director of the National Medical Cyclotron in March 1992, the Environmental Science Program, Ansto agreed to undertake a program of measurements to derive a consequence analysis for a potential accident at the facility. Such an assessment involved :

1. Definition of the source term i.e. amount and type of radionuclides which may be released to the atmosphere in the potential accident.
2. Definition of adverse atmospheric dispersion conditions and their frequency of occurrence.
3. Estimates of atmospheric dispersion from the source to critical receptors.
4. Calculation of the estimated radiation doses at the critical receptor locations.

Source terms for the potential accident have been estimated as a result of a maximum credible accident scenario. Conservative assumptions were made about breakdown in systems to prevent environmental releases of radioactivity in order to maximise the amount available for release (Clark et al 1994). In order to study the adverse meteorological conditions which might lead to worst case dispersion conditions, it is necessary to install monitoring stations in the immediate environment. The geographical location of the National Medical Cyclotron (NMC) building which is surrounded by a complexity of buildings of various shapes and sizes (Figure 1) makes collection of representative meteorological data very difficult. In addition, the definition of worst case dispersion conditions will be determined by the influence of these buildings on the NMC environment.

When undertaking environmental impact assessments in areas of homogeneous or complex terrain, conventional atmospheric transport and dispersion models can be used. However, in areas with special microclimatic effects due to large buildings, other methods are necessary to assess environmental impacts of an operation. For the purposes of the NMC studies, special atmospheric tracer studies were conducted to measure real *in-situ* atmospheric dilution factors for application to the potential accident scenario (Clark et al 1994). In the current report there is a description of the instrumentation and calibration procedures used in an attempt to measure high quality meteorological data collected over a longer period. This is followed by a discussion of the wind, temperature and atmospheric stability statistics.

2. INSTRUMENTATION, CALIBRATION PROCEDURES AND DATA QUALITY

In order to differentiate between local building induced microclimatic influences and the background meteorological conditions, two locations were chosen for installation of meteorological stations (Figure 1). The first was on top of the plant room roof (height of 8.65m above ground level) in the National Medical Cyclotron building, immediately adjacent to the main ventilation chimney stack; any potential accidental release will take place from this stack. The second location for a meteorological station was on the plant room roof (49m above ground level) at the eastern end of the Queen Mary Nursing Home (QMNH), 30 m to the west-south-west of the Cyclotron building. The purpose of this location was to monitor the ambient conditions, without influence of the local buildings. At both locations a 10 metre tower was installed with wind speed and direction sensors at the top and temperature measured in a naturally ventilated solar radiation screen at 9 m above the roof. Climatronics WMIII brand sensors were used for the wind measurements and a solid state AD 590 integrated circuit device for the temperature measurements.

The analogue (wind direction and temperature) and digital (wind speed) signals were input to a Datataker 50 datalogger which sampled every five (5) seconds and was programmed to calculate statistics on the signals each 15 minutes. The statistics calculated in the Datataker are shown in Table 1. Data collection commenced at both stations on July 31, 1992 but a problem in the QMNH datalogger meant that data were not recorded there until August 27, 1992. The performance of both the transducers and datalogger have been less than satisfactory. In order to commence the study at the earliest possibility, anemometers with old wind direction detecting potentiometers were installed without refurbishment; the bearings on the wind speed transducers were refurbished. It was not possible to obtain replacements for these specialised potentiometers until late in 1992 and these were installed on January 14, 1993. Then it was discovered that the Datataker operating system had a problem which caused a further two weeks of lost data. Subsequently the manufacturers have provided a later version of the operating system but other priorities meant a delay in installation. Corrections were made to the software to overcome these operating system problems.

During the atmospheric tracer studies conducted in late August and early September, 1993 it was discovered that the Cyclotron building wind direction measurements on the Datataker differed from general observations. When the anemometer was removed for calibration, it was found that the wind vane shaft had come loose from the potentiometer. It was then necessary to search back through the previous data to determine when this may have occurred. In order to do this, wind direction differences between the QMNH and NMC 15 minute average data were scanned from February 1, 1993 to determine when large differences could be identified. To our dismay it was discovered that bad wind direction data had been recorded on the Cylotron building after May 28, 1993. The only excuse was that pressure of other work had prevented regular inspection and correlation of the data from both stations, which is a warning for other similar studies in future. Therefore, the data available for discussion can be summarised as follows :

- Wind direction - QMNH 1-2-93 to 8-9-93; NMC 1-2-93 to 28-5-93.
- Wind speed - QMNH 1-8-92 to 8-9-93; NMC 1-8-92 to 8-9-93.
- Temperature - QMNH 1-8-92 to 8-9-93; NMC 1-8-92 to 8-9-93.

The installation of sensitive anemometers in an urban, coastal location can lead to problems in collection of high quality data. At the Camperdown site there was obvious corrosion of externally exposed components, much greater than has been observed in other studies at Lucas Heights, 25km to the south-west. This could have been due to the higher salt content in the air as sea breezes regularly passed over the site. In addition, higher air pollution levels with possible acid chemicals could have been a contributing factor. This external corrosion of the transducers and tower components was also reflected in the observed deterioration of the wind speed transducer bearings. The wind speed transducers were calibrated in the low speed wind tunnel at Lucas Heights. Between late August 1992 and September 1993 there was an increase in the starting speed (threshold) of the NMC anemometer from 0.21 to 0.61 m s^{-1} and the output response to wind speed was reduced. The QMNH anemometer showed a similar trend although the threshold change was reduced, possibly due to more fine particulates (dust) in the air nearer the ground where the Cyclotron anemometer was located. Several attempts were made to calibrate the temperature sensors both prior to the study and *in-situ*. Satisfactory calibrations were made using a variable temperature water bath at the completion of the study.

3. METEOROLOGICAL DATA ANALYSES

The atmospheric tracer studies conducted at the Cyclotron building (Clark et al 1994) revealed some important influences of the nearby buildings on the atmospheric dispersion patterns. The tall Queen Mary Nursing Home and the Cyclotron building itself caused a rapid downward movement in the tracer plume and some local air flow patterns near ground level which indicated significant eddies developed against the general wind flow direction. Such short term observations could also be reflected in the longer term wind statistics, although the detailed wind patterns implied from the tracer studies will not be studied in the current report. The wind, temperature and atmospheric stability data discussed below are based on the 15 minute average statistics calculated in the datalogger.

3.1 Wind Statistics

The 15 minute scalar averaged wind speed and vector averaged direction data have been summarised as Bailley-type wind roses in which there is information on the frequency distributions of speeds and directions by time of day and season. In Figures 2 (NMC) and 3 (QMNH) the February, 1993 data are plotted as summer wind roses. It is apparent the wind direction distributions on the QMNH are turned anti-clockwise when compared to the lower Cyclotron building. This is consistent with the Ekman spiral variations of wind direction within the planetary boundary layer in the Southern Hemisphere (Stull 1988). If the QMNH is representative of the background flow across the site then there is a uniform distribution of winds from the north-west through north-north-east sectors before 0600 EST with a secondary peak from the south-south-west to south sectors. The south-south-west winds persist into the afternoon when the sea breeze from the east-north-east to north-east sectors are observed on 38% of occasions. These sea breeze winds gradually turn towards the north-north-east with time; a peak of 22% is still observed during the period 2100 to 2400 EST. A similar distribution of winds is observed on the Cyclotron building but they are turned clockwise with respect to those on QMNH and have lower wind speeds. This turning of the sea breeze wind direction more parallel with the coastline direction is consistent with the effects of Coriolis forces on the air trajectories as the sea breeze intensifies during the afternoon (Atkinson 1981, McGrath 1972). Similar effects have been observed by Clark (1985) at Lucas Heights.

In Autumn there is a more extensive dataset taking in the whole season at both stations. Winds from the north predominate between midnight and 1200 EST on the NMC (Figure 4) and from the north-north-west on the QMNH (Figure 5). There is also a small secondary peak in the NMC distribution from the west to south-west sector which could be indicative of localised drainage flow although not necessarily the Parramatta River drainage wind flow which has been observed through a 50 to 150m deep layer (Hyde et al 1982). Between 0900 and 1800 EST up to 20% of the winds are obeserved from the south-south-west sector on the QMNH and from the south-west on the NMC building. A significant sea breeze component is also observed from the east to north-east sectors during this same period. Again the sea breeze appears to gradually turn towards the more northerly sectors with time during the afternoon and into the autumn evening.

A full season of winter data was available only for the QMNH station (Figure 6). In common with the autumn wind roses (Figure 5), in winter the night to early morning period was dominated by winds from the north-north-west sector. These winds may be associated with the off-land drainage of cool nocturnal air down the Parramatta river valley, although such drainage winds might be expected to have a more westerly component. Winds from the south-west develop during the day. During winter when the driving force of solar radiational heating is diminished, there is still an apparent sea breeze influence with winds from the east-north-east to north-north-east sector observed to develop relatively late (1500 to 1800 EST) but then persisting into the evening.

Variations of wind directions between the QMNH and NMC sites are further investigated in terms of the influence of nearby buildings on the wind direction mean and standard deviation (σ_θ) data. Buildings significantly higher than the NMC building are located in the following upwind sectors : 96 to 137° - King George V Hospital (32.5 to 40.8 m high); 232 to 266° - Queen Mary Nursing Home (42.5 to 48.5 m high); 311 to 34° - Queen Elizabeth II Rehabilitation Centre (12.5 to 22.5 m high). Two sectors in which there were no significant upwind building influences or a reasonably homogeneous upwind fetch were chosen for comparison. From Figure 1, these conditions were observed in the 34 to 90° and 137 to 221° sectors; these sectors do not exactly correspond with the building sector cut offs due to possible building edge effects on the turbulence. The effect of wind speed was also investigated by subdividing data into the QMNH winds < 2.5 m s^{-1} (Table 2) and > 2.5 m s^{-1} (Table 3). for the period February 1 to May 28, 1993.

Initially it was thought that the influence of the closest building, the QMNH, would lead to the most significant variations. In terms of all statistics, the QMNH building appears to have a similar or lower impact on the Cyclotron wind direction data to other nearby buildings. The average wind direction difference between the higher and lower sites is near 30° for the lighter winds and 23° for stronger winds. However, the major differences lie in the shape of the distribution of the wind direction differences (the standard deviation). At lower wind speeds there is a much broader distribution i.e. under these conditions there is a probability of having a much larger wind direction change with height at this site. Whether this is a function of the building influences or the more general occurrence of meandering wind directions for light wind speed conditions remains unclear.

By comparison with the sectors in which there were upwind building influences, for no building influences the average wind direction differences were similar if not somewhat larger in the case of winds from the 137 to 221° sector. However, at the stronger speeds there is a significant decrease in the spread of the distribution of wind direction differences for the sector not influenced by buildings. In this case the standard deviations vary between 9 and 12° for the sectors without buildings and between 22 and 41° for the building influenced wind direction differences.

The standard deviation of wind directions averaged over 15 minutes were also studied to detect building influences. Here again there was a similar trend, although winds from the sector in which the King George V Hospital was located had larger average values of σ_θ and a broader distribution than other sectors. With stronger wind speeds at the higher site on the QMNH (Table 3) the average values of σ_θ between 13 and 27° for all sectors probably indicated the influence of more general surface roughness of the city landscape. Likewise with higher wind speeds, the smaller average value of σ_θ and its frequency distribution on the Cyclotron Building may be due to the smaller angle the QMNH building subtends at the Cyclotron when compared to the other sectors.

The influences of surface roughness are also observed in the wind speed statistics. In this case the longer dataset from September 1992 to September 1993 is available for analysis. Data have been summarised by month in three hour blocks during the day (Table 4). In general the daytime wind speeds are higher than those at night with the summer months having 15 minute average wind speeds observed at near 7 m s^{-1} during the afternoon when the sea breeze is most likely. Under these conditions the average difference in wind speed between the QMNH and NMC buildings is greatest with the QMNH speeds higher by 2 m s^{-1} on average. In these cases there is a narrow spread in the speed difference distribution (0.8 m s^{-1}) by comparison with the June to September months when the average difference during the afternoon becomes similar to the standard deviation, above 1.1 m s^{-1}. As was expected, the afternoon wind speeds in winter are lower than in summer when the sea breezes are more intense.

3.2 Atmospheric Dispersion Parameters

From the discussion above it is apparent that there are building and other surface roughness influences at the National Medical Cyclotron site which produce considerable atmospheric turbulence. If the Mitchell and Timbre (1979) scheme is applied to define the prevailing atmospheric dispersion stability conditions, the turbulence influences on σ_θ become most important. In this scheme, values of σ_θ are related to the wind speed in order to define the Pasquill stability category (Pasquill 1961, Gifford 1961). In effect this scheme is a "split-sigma" approach in which different atmospheric dispersion categories can be assigned to the vertical and horizontal (cross-wind) directions. When applied in areas of smooth terrain, this method of determination of the stability categories allows for large values of (σ_θ) observed under very stable, night time atmospheric conditions to have a corresponding very stable type F or G Pasquill category for vertical dispersion. However, in the urban environment large values of σ_θ can occur because of the building induced turbulence, thus biasing the distribution to the more stable Pasquill stability categories in the vertical direction.

In Table 5 this is most marked for data from the National Medical Cyclotron building. In this case at night there are predicted to be over 40% of Pasquill categories F and G for dispersion in the vertical direction. The larger percentages of the most unstable categories A and B for horizontal dispersion at night directly reflects the occurrence of large values of σ_θ. In the daytime large values of σ_θ are typical of unstable, turbulent conditions in both the horizontal and vertical directions in this scheme. Over 97% of all observations are predicted to be in the unstable categories A to C.

By contrast the data from the top of the Queen Mary Nursing Home (Table 6) indicates σ_θ night values more typical of slightly unstable through neutral to slightly stable atmospheric conditions (C to E). The distribution of Pasquill stability categories in the daytime is reasonably uniform across the unstable categories A to C.

3.3 Temperature Statistics

Temperatures have been summarised as monthly averages, by three hour time periods through the day for a 12 month period from September 1992 to August 1993; there was uncertainty in the QMNH calibration between September and November, 1992 so these data were eliminated. The Cyclotron building tower temperature statistics are shown in Table 7 with those from the QMNH in Table 8; the average and extreme values in these tables are based on the 15 minute average data. The average maximum and minimum Cyclotron building temperatures in January and July are consistent with the long term 50 percentile values from the Sydney Observatory (NATMAP 1986). The extreme value of temperature in February 1993 of 44.7°C on the Cyclotron building tower was close to the record high temperature for Sydney and could have been over estimated due to convective heat from the building roof.

In Table 9 it is interesting to note that the most stable (≥-0.4°C per 40m) temperature differences were observed at night in December 1992 and January 1993. In all other months unstable conditions were observed through both day and night. An analysis of the frequency of occurrence of temperature differences (Table 10) also indicates that unstable conditions exist in the vertical direction for over 85% of all times. These observations complement the previous discussion on atmospheric dispersion categories using the Mitchell and Timbre (1979) approach in which the majority of horizontal dispersion categories were also predicted to be in the unstable regime (i.e. A to C). Such observations are consistent with the presence of an urban heat island in which buildings retain their daytime heat and with other athropogenic heat and air pollution sources cause a modification to a less stable vertical temperature structure in the lower atmosphere at night (Munn 1966, Stull 1988). However, it does suggest that the Mitchell and Timbre (1979) scheme may be inappropriate for definition of the vertical dispersion stability category based on the measurements of σ_θ in an urban environment.

4. SUMMARY

The study of the atmospheric dispersion conditions at the National Medical Cyclotron in Camperdown, N.S.W. presented a number of difficulties. As a result, the performance of the instrumentation was below that expected for an environmental impact study. In spite of this, a number of important features emerged. The first was that the influence of large buildings in the immediate vicinity of the Cyclotron building was not of overwhelming importance, but rather there was a more general influence of the surface roughness and thermal characteristics of the urban area which were dominant. These general influences affected the observed wind direction turbulence and temperature gradient measurements, thus leading to a predominance of unstable to neutral atmospheric stability, horizontal dispersion categories. Application of the Mitchell and Timbre (1979) scheme at night in this urban environment seemed inappropriate for prediction of vertical dispersion stability categories. Instead of identifying wind meandering under very stable atmospheric conditions the scheme overpredicts the highly stable Pasquill categories (E to F) due to enhanced values of σ_θ resulting from building effects, etc..

The well mixed, turbulent lower atmosphere meant that wind direction variations with height above the Cyclotron building were consistent with the Ekman spiral variations more typical of non-urban conditions. During the autumn and early winter periods, night time winds were most frequently observed from the north-north-west in the free atmosphere above the building influences. During the day sea breezes were observed to develop in all seasons although they were more intense and persistent in the summer and autumn months. The sea breezes initially were observed from the east-north-east sector and gradually turned towards the north later in the day and into the evening. In general the Cyclotron winds were observed from a direction turned clockwise with respect to those on the Queen Mary Nursing Home.

5. ACKNOWLEDGEMENTS

The support of Mr. Bob Barnes and other members of the National Medical Cyclotron staff is gratefully acknowledged.

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Parameter Index	DAS Signal Identifier	Statistic type Identifier	Statistic
1	T	M	Average
2	U	M	Scalar average
3	U	D	Scalar standard deviation
4	D	M	Scalar average
5	D	D	Scalar standard deviation
6	U	VM	Vector average
7	U	VD	Vector standard deviation
8	D	VM	Vector average
9	D	VD	Vector standard deviation

D = Wind direction.
T = Temperature.
U = Wind speed.

National Medical Cyclotron meteorological study - data acquisition system parameter statistics.

Table 1

Statistics	Sector (degs.) Building influences 96-137	232-266	311- 34	No buildings 34- 90	137-221
WD (QMNH) - WD (CYC)					
Average	-28.8	-31.1	-27.2	-23.0	-46.2
Standard Deviation	55.7	35.9	75.5	53.8	26.3
No. of Obs.	148.0	213.0	1834.0	118.0	392.0
Sigma (CYC)					
Average	51.4	25.2	28.0	32.0	25.8
Standard Deviation	25.1	17.9	16.7	22.0	17.1
No. of Obs.	148.0	213.0	1834.0	118.0	392.0
Sigma (QMNH)					
Average	30.1	30.8	16.9	32.0	22.7
Standard Deviation	15.7	16.1	11.4	24.3	16.1
No. of Obs.	148.0	213.0	1834.0	118.0	392.0

CYC = Cyclotron building values
QMNH = Queen Mary Nursing Home values
WD = Wind direction (degs.)
Sigma = Standard deviation of wind direction (degs.)
Dates : 10293 to 280593

Building influences on statistics of wind direction - wind speeds < 2.5 m s^{-1}.

Table 2

Statistics	Building influences			No buildings	
	Sector (degs.)				
	96-137	232-266	311- 34	34- 90	137-221
WD(QMNH) - WD(CYC)					
Average	-23.4	-28.3	-18.4	-20.9	-37.2
Standard Deviation	33.5	22.0	40.7	9.0	12.3
No. of Obs.	305.0	319.0	2512.0	1199.0	2987.0
Sigma (CYC)					
Average	58.7	18.8	24.9	19.7	20.0
Standard Deviation	18.4	7.9	14.0	5.2	8.9
No. of Obs.	305.0	319.0	2512.0	1199.0	2987.0
Sigma (QMNH)					
Average	26.9	25.2	13.4	14.9	16.8
Standard Deviation	8.7	10.5	6.3	5.3	5.3
No. of Obs.	305.0	319.0	2512.0	1199.0	2987.0

CYC = Cyclotron building values
QMNH = Queen Mary Nursing Home values
WD = Wind direction (degs.)
Sigma = Standard deviation of wind direction (degs.)
Dates : 10293 to 280593

Building influences on statistics of wind direction - wind speeds > 2.5 m s^{-1}.

Table 3

Wind Speed (m/s) Statistics

Times (EST)

Year	Month	Statistic	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400
1992	September	Ucyc	2.7	2.8	3.2	4.2	5.0	4.6	3.8	3.0
		Sigma	1.0	1.1	1.5	2.0	2.0	2.1	1.5	1.1
		No.	360.	360.	360.	357.	360.	360.	360.	360.
		Uqmnh	3.9	3.7	3.8	5.3	6.6	6.3	5.2	4.3
		Sigma	1.7	1.6	1.9	2.6	2.7	2.7	2.2	1.9
		No.	360.	360.	360.	360.	360.	360.	360.	360.
		Uqmnh-Ucyc	1.2	1.0	0.7	1.1	1.6	1.8	1.4	1.3
		Sigma	1.1	0.8	0.8	1.1	1.1	1.2	1.1	1.1
		No.	360.	360.	360.	357.	360.	360.	360.	360.
1992	October	Ucyc	2.8	2.4	3.3	4.5	4.9	4.8	3.9	3.1
		Sigma	1.2	1.2	1.6	2.1	1.9	2.0	1.9	1.4
		No.	372.	372.	372.	372.	372.	372.	372.	372.
		Uqmnh	3.7	3.3	4.0	5.5	6.4	6.6	5.4	4.1
		Sigma	1.7	1.8	2.2	2.7	2.3	2.5	2.4	1.8
		No.	372.	372.	372.	370.	372.	372.	372.	372.
		Uqmnh-Ucyc	0.9	0.9	0.7	1.0	1.5	1.7	1.5	1.0
		Sigma	0.8	0.9	0.9	0.8	0.8	1.0	0.9	0.7
		No.	372.	372.	372.	370.	372.	372.	372.	372.
1992	November	Ucyc	2.9	2.8	3.4	4.4	5.2	5.2	4.0	3.4
		Sigma	1.6	1.2	1.5	1.9	1.9	2.1	2.0	1.6
		No.	360.	360.	360.	360.	359.	360.	360.	360.
		Uqmnh	3.7	3.4	4.2	5.3	6.6	6.9	5.3	4.4
		Sigma	2.2	1.7	2.0	2.3	2.3	2.5	2.5	2.2
		No.	360.	360.	360.	359.	359.	360.	360.	360.
		Uqmnh-Ucyc	0.8	0.7	0.7	1.0	1.5	1.6	1.3	1.0
		Sigma	0.8	0.7	0.8	0.7	0.7	0.8	0.8	0.8
		No.	360.	360.	360.	359.	358.	360.	360.	360.
1992	December	Ucyc	2.6	2.3	3.0	3.8	4.7	4.4	3.5	2.8
		Sigma	1.3	1.1	1.4	1.4	1.3	1.3	1.3	1.1
		No.	204.	204.	204.	204.	212.	215.	204.	204.
		Uqmnh	3.6	3.2	3.7	4.9	6.3	6.2	5.2	4.0
		Sigma	2.1	1.8	2.1	2.1	1.9	1.9	2.2	2.1
		No.	264.	264.	263.	252.	262.	264.	264.	264.
		Uqmnh-Ucyc	0.5	0.5	0.4	0.9	1.5	1.7	1.3	0.9
		Sigma	0.6	0.5	0.7	0.8	0.6	0.6	0.9	0.8
		No.	204.	204.	204.	204.	212.	215.	204.	204.
1993	January	Ucyc	2.6	3.2	3.6	4.2	5.0	4.5	3.3	2.9
		Sigma	1.7	1.9	2.0	1.9	1.4	1.3	1.5	2.3
		No.	144.	144.	144.	134.	131.	132.	132.	132.
		Uqmnh	3.7	4.4	4.6	5.6	7.0	6.7	5.2	4.2
		Sigma	2.2	2.3	2.6	2.4	2.0	1.9	2.4	3.0
		No.	144.	144.	144.	138.	132.	132.	132.	132.
		Uqmnh-Ucyc	1.2	1.2	1.0	1.2	2.0	2.2	1.8	1.3
		Sigma	0.7	0.6	0.7	0.7	0.8	0.8	1.0	0.9
		No.	144.	144.	144.	134.	131.	132.	132.	132.

Monthly wind speed statistics versus time of day - September 1992 to August 1993.

Table 4

Wind Speed (m/s) Statistics

Year	Month	Statistic	Times (EST) 0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400
1993	February	Ucyc	2.5	2.3	3.0	4.1	4.8	4.5	3.9	3.1
		Sigma	1.6	1.4	1.9	2.1	1.8	1.6	2.0	1.4
		No.	324.	324.	324.	324.	333.	336.	336.	336.
		Uqmnh	3.5	3.1	3.8	5.4	6.6	6.4	5.6	4.5
		Sigma	2.1	1.9	2.6	2.7	2.3	2.0	2.7	2.0
		No.	324.	324.	324.	329.	335.	336.	336.	336.
		Uqmnh-Ucyc	0.9	0.8	0.8	1.3	1.8	1.9	1.7	1.3
		Sigma	0.7	0.7	0.8	0.9	0.8	0.8	1.0	0.8
		No.	324.	324.	324.	324.	332.	336.	336.	336.
1993	March	Ucyc	2.2	2.2	2.8	3.9	4.5	4.4	3.4	2.6
		Sigma	1.2	1.3	1.6	1.9	1.9	1.9	1.7	1.5
		No.	372.	372.	372.	370.	372.	372.	372.	372.
		Uqmnh	3.1	3.0	3.5	5.0	6.0	6.0	4.9	3.7
		Sigma	1.9	1.7	2.2	2.5	2.4	2.3	2.2	2.0
		No.	372.	372.	372.	372.	372.	372.	372.	372.
		Uqmnh-Ucyc	0.9	0.8	0.7	1.1	1.4	1.7	1.5	1.1
		Sigma	0.8	0.7	0.9	0.8	0.7	0.6	0.8	0.8
		No.	372.	372.	372.	370.	372.	372.	372.	372.
1993	April	Ucyc	2.1	2.1	2.4	3.4	4.1	3.9	2.7	2.2
		Sigma	1.3	1.0	1.0	1.7	1.9	1.7	1.4	1.2
		No.	360.	360.	360.	360.	360.	360.	360.	360.
		Uqmnh	2.9	2.8	2.9	4.1	5.2	5.3	3.9	3.2
		Sigma	1.8	1.5	1.4	2.3	2.4	2.0	1.8	1.8
		No.	360.	360.	360.	359.	360.	360.	360.	360.
		Uqmnh-Ucyc	0.8	0.7	0.5	0.7	1.1	1.5	1.2	1.0
		Sigma	0.7	0.7	0.7	0.6	0.6	0.5	0.6	0.7
		No.	360.	360.	360.	359.	360.	360.	360.	360.
1993	May	Ucyc	2.0	2.1	2.3	3.1	3.6	3.3	2.5	2.0
		Sigma	0.9	1.0	1.0	1.6	1.9	1.4	1.2	1.0
		No.	372.	372.	372.	372.	372.	372.	372.	372.
		Uqmnh	2.9	3.1	3.1	3.7	4.5	4.4	3.7	3.0
		Sigma	1.2	1.4	1.3	2.0	2.3	1.8	1.7	1.3
		No.	372.	372.	372.	372.	372.	372.	372.	372.
		Uqmnh-Ucyc	0.9	1.0	0.8	0.7	0.9	1.1	1.2	1.0
		Sigma	0.7	0.8	0.8	0.6	0.7	0.6	0.8	0.7
		No.	372.	372.	372.	372.	372.	372.	372.	372.
1993	June	Ucyc	2.4	2.3	2.2	2.9	3.7	3.0	2.3	2.2
		Sigma	1.2	1.0	0.9	1.3	1.9	1.7	1.4	1.1
		No.	360.	360.	360.	359.	359.	360.	360.	360.
		Uqmnh	3.6	3.6	3.4	4.1	5.1	4.4	3.8	3.4
		Sigma	1.6	1.3	1.5	2.1	2.9	2.3	1.7	1.5
		No.	360.	360.	360.	360.	358.	360.	360.	360.
		Uqmnh-Ucyc	1.2	1.3	1.2	1.2	1.4	1.3	1.5	1.3
		Sigma	0.9	0.9	1.1	1.2	1.5	1.1	0.9	0.8
		No.	360.	360.	360.	359.	357.	360.	360.	360.

TABLE 4 contd.

Wind Speed (m/s) Statistics

Times (EST)

Year	Month	Statistic	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400
1993	July	Ucyc	1.7	2.0	2.1	2.6	3.3	3.1	2.3	1.9
		Sigma	0.8	0.8	1.0	1.6	1.7	1.7	1.3	1.1
		No.	372.	372.	372.	372.	372.	372.	372.	372.
		Uqmnh	2.7	2.8	2.8	3.2	4.1	4.1	3.5	3.0
		Sigma	1.1	1.2	1.3	1.9	2.0	2.1	1.6	1.3
		No.	372.	372.	372.	372.	371.	372.	372.	372.
		Uqmnh-Ucyc	1.0	0.9	0.7	0.7	0.9	1.0	1.2	1.1
		Sigma	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.6
		No.	372.	372.	372.	372.	371.	372.	372.	372.
1993	August	Ucyc	2.2	2.2	2.6	3.2	3.8	3.7	2.7	2.6
		Sigma	1.1	0.9	1.1	1.4	1.5	1.7	1.4	1.4
		No.	372.	372.	372.	372.	371.	372.	372.	372.
		Uqmnh	3.5	3.1	3.5	4.0	4.9	5.2	4.1	3.9
		Sigma	1.7	1.3	1.3	1.9	2.2	2.3	1.9	1.9
		No.	372.	372.	372.	372.	371.	372.	372.	372.
		Uqmnh-Ucyc	1.4	1.0	0.9	0.8	1.1	1.5	1.4	1.4
		Sigma	1.1	0.8	0.8	0.9	1.0	1.0	0.9	0.9
		No.	372.	372.	372.	372.	370.	372.	372.	372.

TABLE 4 contd.

Frequency (%) of occurrence of
Pasquill stability categories

	Night		Day	
Stability	Sigy	Sigz	Sigy	Sigz
A	31.98	0.00	41.54	41.54
B	24.08	0.00	30.60	30.60
C	33.19	0.00	25.48	25.48
D	8.53	38.07	1.47	1.47
E	0.98	20.57	0.51	0.51
F	0.31	13.63	0.17	0.17
G	0.92	27.73	0.24	0.24

Night = > Sunset - 1 hour
Day = > Sunrise + 1 hour

Sigy = These stability categories relevant to horizontal diffusion
Sigz = These stability categories relevant to vertical diffusion

Dates : 10293 to 280593

Frequency of occurrence of Pasquill stability categories for the horizontal and vertical directions - Cyclotron building.

Table 5

Frequency (%) of occurrence of
Pasquill stability categories

	Night		Day	
Stability	Sigy	Sigz	Sigy	Sigz
A	11.36	0.00	29.52	29.52
B	9.96	0.00	22.54	22.54
C	30.68	0.00	34.25	34.25
D	36.83	66.58	12.57	12.57
E	10.24	20.44	1.12	1.12
F	0.89	6.02	0.00	0.00
G	0.04	6.96	0.00	0.00

Night = > Sunset - 1 hour
Day = > Sunrise + 1 hour

Sigy = These stability categories relevant to horizontal diffusion
Sigz = These stability categories relevant to vertical diffusion

Dates : 10293 to 80993

Frequency of occurrence of Pasquill stability categories for the horizontal and vertical directions - Queen Mary Nursing Home.

Table 6

Dates : 10992 to 310893

Cyclotron dry bulb temperature (deg.c)

Time (EST.)

month	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400	average minimum	average maximum	extreme minimum	extreme maximum
September 1992	11.6	10.6	12.0	16.7	18.0	16.5	14.5	13.1	9.3	19.2	5.4	24.2
	2.6	2.8	2.9	2.8	3.0	3.0	2.4	2.4	standard deviations			
	360.	360.	360.	357.	360.	360.	360.	360.	number of observations			
October 1992	14.3	13.4	15.2	18.3	19.0	17.7	16.6	15.7	12.6	20.3	6.8	28.5
	2.7	2.8	3.0	3.5	3.2	2.7	2.7	2.7	standard deviations			
	372.	372.	372.	372.	372.	372.	372.	372.	number of observations			
November 1992	15.6	14.7	17.2	20.2	20.6	19.7	18.0	17.0	13.8	22.0	8.7	30.3
	2.9	2.9	3.3	3.9	3.8	3.5	3.2	3.3	standard deviations			
	360.	360.	360.	360.	359.	360.	360.	360.	number of observations			
December 1992	19.4	19.0	22.0	24.8	24.9	22.9	21.7	21.0	18.5	26.0	12.8	30.9
	2.4	2.4	2.9	3.1	3.1	2.3	2.3	2.0	standard deviations			
	204.	204.	204.	204.	212.	215.	204.	204.	number of observations			
January 1993	20.3	19.3	21.4	23.2	23.8	22.9	21.9	21.2	18.7	25.1	16.0	29.5
	1.8	1.6	2.8	3.2	3.0	2.6	2.6	2.1	standard deviations			
	144.	144.	144.	134.	131.	132.	132.	132.	number of observations			
February 1993	21.2	20.5	22.1	25.5	26.7	25.4	23.3	22.5	19.6	28.4	13.2	44.7
	2.4	2.5	3.0	3.9	4.5	3.5	2.6	2.6	standard deviations			
	324.	324.	324.	324.	333.	336.	336.	336.	number of observations			
March 1993	18.7	17.8	18.9	22.5	23.8	22.5	20.8	19.7	16.9	24.7	13.0	29.3
	1.8	1.8	2.1	2.1	2.2	1.8	1.4	1.7	standard deviations			
	372.	372.	372.	370.	372.	372.	372.	372.	number of observations			
April 1993	17.6	16.6	16.9	21.2	23.2	21.4	19.7	18.7	15.4	24.2	12.1	33.5
	1.7	1.9	2.0	2.4	3.6	3.0	1.8	1.7	standard deviations			
	360.	360.	360.	360.	360.	360.	360.	360.	number of observations			
May 1993	13.5	12.4	12.7	17.1	19.6	18.4	16.7	15.2	11.3	20.3	6.8	26.9
	2.4	2.5	2.7	2.4	2.6	2.5	2.1	2.2	standard deviations			
	372.	372.	372.	372.	372.	372.	372.	372.	number of observations			
June 1993	10.0	9.1	9.4	13.7	16.2	15.3	13.0	11.2	7.9	17.1	3.8	21.8
	2.7	2.9	2.8	2.4	2.2	2.4	1.8	2.1	standard deviations			
	360.	360.	360.	359.	359.	360.	360.	360.	number of observations			
July 1993	12.2	11.6	11.8	15.0	16.7	15.8	14.3	13.2	10.1	17.9	5.3	21.1
	2.6	3.1	3.2	2.3	1.9	1.7	1.6	2.2	standard deviations			
	372.	372.	372.	372.	372.	372.	372.	372.	number of observations			
August 1993	11.3	10.3	10.8	15.3	17.7	16.5	14.6	13.2	9.3	18.8	4.6	23.7
	2.7	2.7	2.8	2.9	2.6	2.4	2.2	2.4	standard deviations			
	372.	372.	372.	372.	371.	372.	372.	372.	number of observations			

Monthly Cyclotron building temperature statistics versus time of day - September 1992 to August 1993.

Table 7

Dates : 11192 to 310893

QMNH - dry bulb temperature (deg.c)

Time (BST.)

month	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400	average minimum	average maximum	extreme minimum	extreme maximum
November 1992	15.0	14.2	16.0	18.6	19.0	18.5	17.3	16.3	12.8	20.2	0.0	27.9
	2.6	2.6	2.8	3.3	3.2	3.2	3.1	3.0	standard deviations			
	360.	360.	360.	359.	359.	360.	360.	360.	number of observations			
December 1992	18.6	18.6	20.2	22.1	22.1	21.0	20.4	19.8	17.8	23.1	12.0	28.9
	2.6	2.7	2.7	2.9	2.9	2.2	2.2	2.2	standard deviations			
	264.	264.	263.	252.	262.	264.	264.	264.	number of observations			
January 1993	20.4	19.8	20.9	22.4	22.8	22.5	21.9	21.3	19.4	24.1	18.1	26.8
	1.0	0.8	1.7	1.4	1.0	1.4	1.8	1.4	standard deviations			
	108.	108.	108.	102.	96.	96.	96.	96.	number of observations			
February 1993	19.5	18.7	19.8	22.7	23.7	23.0	21.5	20.7	18.0	25.3	12.6	41.1
	2.2	2.3	2.6	3.7	4.4	3.4	2.7	2.6	standard deviations			
	324.	324.	324.	329.	335.	336.	336.	336.	number of observations			
March 1993	17.7	16.8	17.5	20.3	21.5	20.8	19.6	18.7	16.0	22.3	12.2	26.8
	1.7	1.8	1.9	1.9	2.1	1.6	1.4	1.6	standard deviations			
	372.	372.	372.	372.	372.	372.	372.	372.	number of observations			
April 1993	16.7	15.7	15.8	19.3	21.1	19.8	18.8	17.9	14.5	22.0	11.2	31.2
	1.7	1.9	1.8	2.1	3.4	2.8	1.9	1.9	standard deviations			
	360.	360.	360.	359.	360.	360.	360.	360.	number of observations			
May 1993	12.5	11.3	11.4	15.2	17.6	17.0	15.8	14.3	10.4	18.3	6.1	24.4
	2.4	2.5	2.6	2.3	2.4	2.3	2.1	2.2	standard deviations			
	372.	372.	372.	372.	372.	372.	372.	372.	number of observations			
June 1993	9.0	8.2	8.3	11.8	14.4	14.0	12.3	10.4	7.0	15.3	2.9	19.7
	2.6	2.8	2.7	2.4	2.1	2.2	1.7	2.0	standard deviations			
	360.	360.	360.	360.	358.	360.	360.	360.	number of observations			
July 1993	10.8	10.1	10.1	13.0	14.8	14.3	13.3	12.0	8.9	15.7	4.2	19.2
	2.5	2.9	2.9	2.2	1.8	1.5	1.5	2.0	standard deviations			
	372.	372.	372.	372.	371.	372.	372.	372.	number of observations			
August 1993	10.7	9.3	9.5	13.3	15.7	15.1	13.8	12.4	8.3	16.8	3.8	22.1
	2.6	2.6	2.7	2.7	2.4	2.3	2.2	2.4	standard deviations			
	372.	372.	372.	372.	371.	372.	372.	372.	number of observations			

Monthly Queen Mary Nursing Home temperature statistics versus time of day - November 1992 to August 1993.

Table 8

Temperature Difference (QMNH - CYC) Statistics

Year	Month	Statistic	0000-0300	0300-0600	0600-0900	0900-1200	1200-1500	1500-1800	1800-2100	2100-2400
			Times (EST)							
1992	November	Aver.	-0.6	-0.5	-1.2	-1.6	-1.6	-1.2	-0.7	-0.7
		Sigma	0.6	0.7	0.9	1.0	0.9	0.6	0.5	0.5
		No.	360.	360.	360.	359.	358.	360.	360.	360.
1992	December	Aver.	-0.4	0.0	-1.2	-2.1	-2.1	-1.4	-0.9	-0.6
		Sigma	1.0	1.3	1.5	1.2	1.1	0.9	0.7	0.9
		No.	204.	204.	204.	204.	212.	215.	204.	204.
1993	January	Aver.	-0.4	-0.2	-1.6	-2.3	-2.5	-1.7	-1.1	-1.0
		Sigma	0.9	1.0	0.8	0.4	0.3	0.4	0.3	0.4
		No.	108.	108.	108.	98.	96.	96.	96.	96.
1993	February	Aver.	-1.8	-1.8	-2.4	-2.9	-3.0	-2.4	-1.8	-1.7
		Sigma	0.6	0.5	0.7	0.9	0.5	0.5	0.4	0.5
		No.	324.	324.	324.	324.	332.	336.	336.	336.
1993	March	Aver.	-1.0	-0.9	-1.3	-2.1	-2.3	-1.7	-1.1	-1.0
		Sigma	0.3	0.3	0.5	0.4	0.3	0.4	0.2	0.2
		No.	372.	372.	372.	370.	372.	372.	372.	372.
1993	April	Aver.	-0.9	-0.8	-1.1	-1.9	-2.2	-1.6	-1.0	-0.8
		Sigma	0.5	0.6	0.8	0.7	0.5	0.4	0.3	0.4
		No.	360.	360.	360.	359.	360.	360.	360.	360.
1993	May	Aver.	-1.1	-1.0	-1.3	-1.9	-2.0	-1.4	-0.9	-0.9
		Sigma	0.4	0.4	0.4	0.3	0.3	0.4	0.3	0.3
		No.	372.	372.	372.	372.	372.	372.	372.	372.
1993	June	Aver.	-1.0	-0.9	-1.2	-1.9	-1.9	-1.3	-0.8	-0.8
		Sigma	0.5	0.6	0.7	0.3	0.3	0.4	0.4	0.5
		No.	360.	360.	360.	359.	357.	360.	360.	360.
1993	July	Aver.	-1.4	-1.5	-1.7	-2.0	-1.9	-1.5	-1.0	-1.2
		Sigma	1.0	1.0	0.8	0.5	0.5	0.6	0.6	0.8
		No.	372.	372.	372.	372.	371.	372.	372.	372.
1993	August	Aver.	-0.8	-0.9	-1.3	-2.0	-2.0	-1.4	-0.7	-0.8
		Sigma	0.5	0.6	0.5	0.3	0.3	0.5	0.4	0.3
		No.	372.	372.	372.	372.	370.	372.	372.	372.

Monthly temperature difference statistics (QMNH - Cyclotron) versus time of day - November 1992 to August 1993.

Table 9

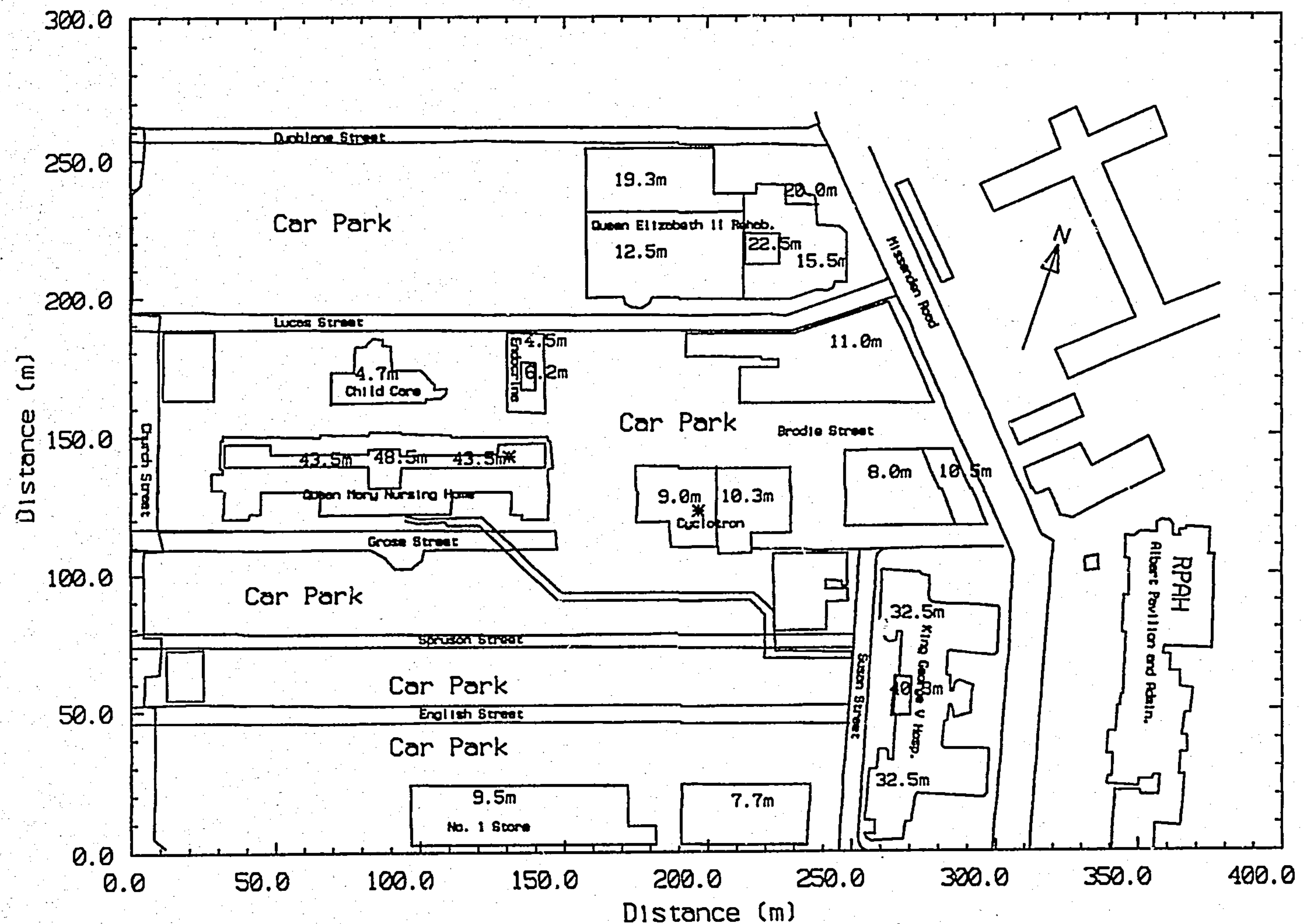
Frequency of occurrence (%) of Temperature Differences (QMNH - CYC)

Temp. Diff. (Deg.C)	Time (EST) 0000 - 0300	0300 - 0600	0600 - 0900	0900 - 1200	1200 - 1500	1500 - 1800	1800 - 2100	2100 - 2400
<-0.6	76.69	75.94	89.64	97.24	98.62	96.55	80.40	78.87
-0.6 to -0.4	8.61	7.74	3.78	0.47	0.28	1.80	10.21	8.71
-0.4 to -0.2	5.68	4.90	1.81	0.44	0.09	0.56	5.06	5.62
-0.2 to 0.0	3.71	3.62	0.97	0.16	0.03	0.40	2.37	3.56
0.0 to 0.2	1.40	1.72	0.72	0.09	0.06	0.28	0.75	1.09
0.2 to 0.4	1.09	0.87	0.37	0.09	0.06	0.03	0.44	0.72
0.4 to 0.6	0.78	1.00	0.47	0.28	0.13	0.00	0.25	0.34
> 0.6	2.03	4.21	2.25	1.22	0.72	0.37	0.53	1.09

Frequency of occurrence of temperature differences (QMNH - Cyclotron) versus time of day.

Table 10

Site Plan and Building Heights



* = Locations of the meteorological stations

Site plan and building heights surrounding the National Medical Cyclotron

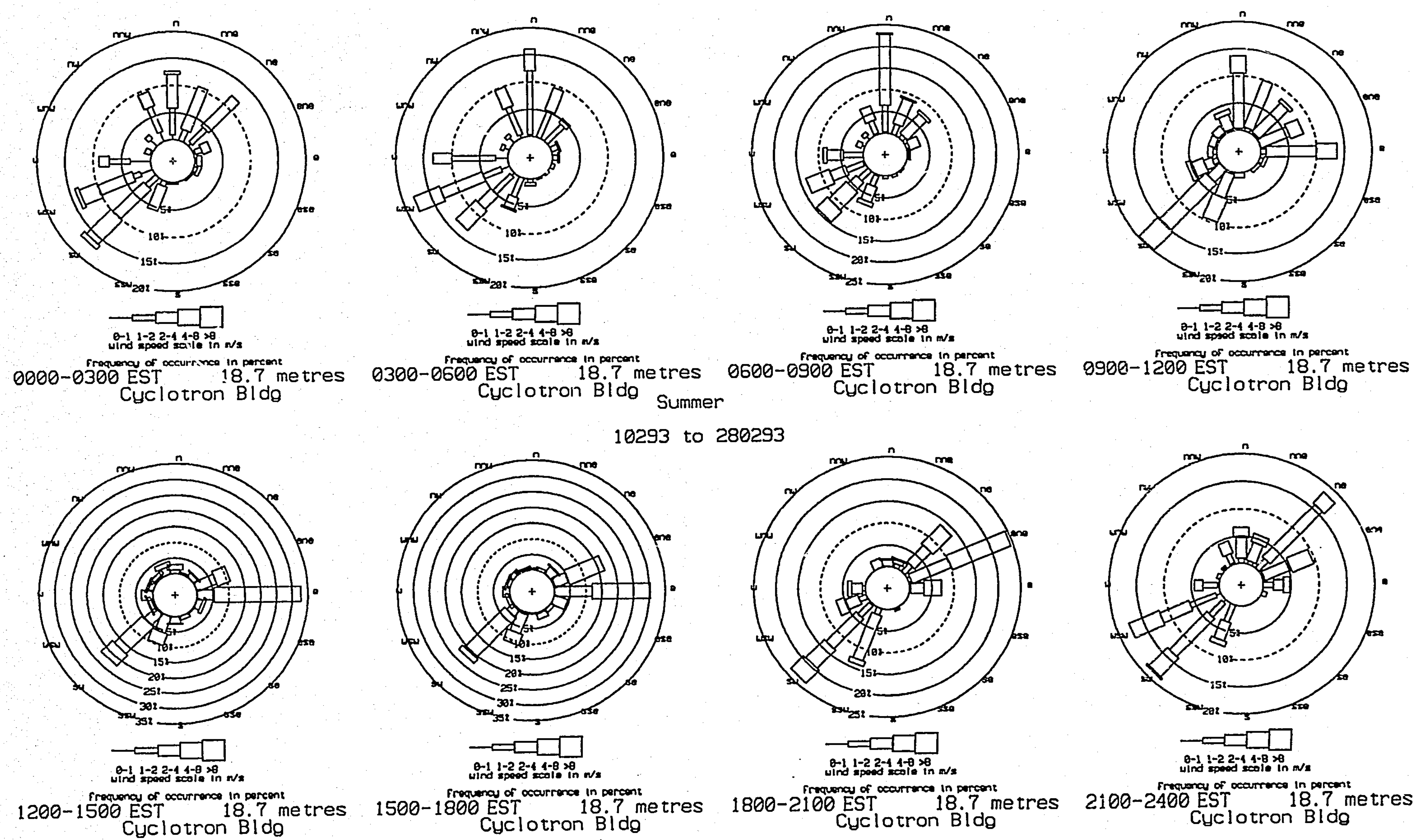


Figure 2 - Summer Bailley-type wind roses - Cyclotron Building.

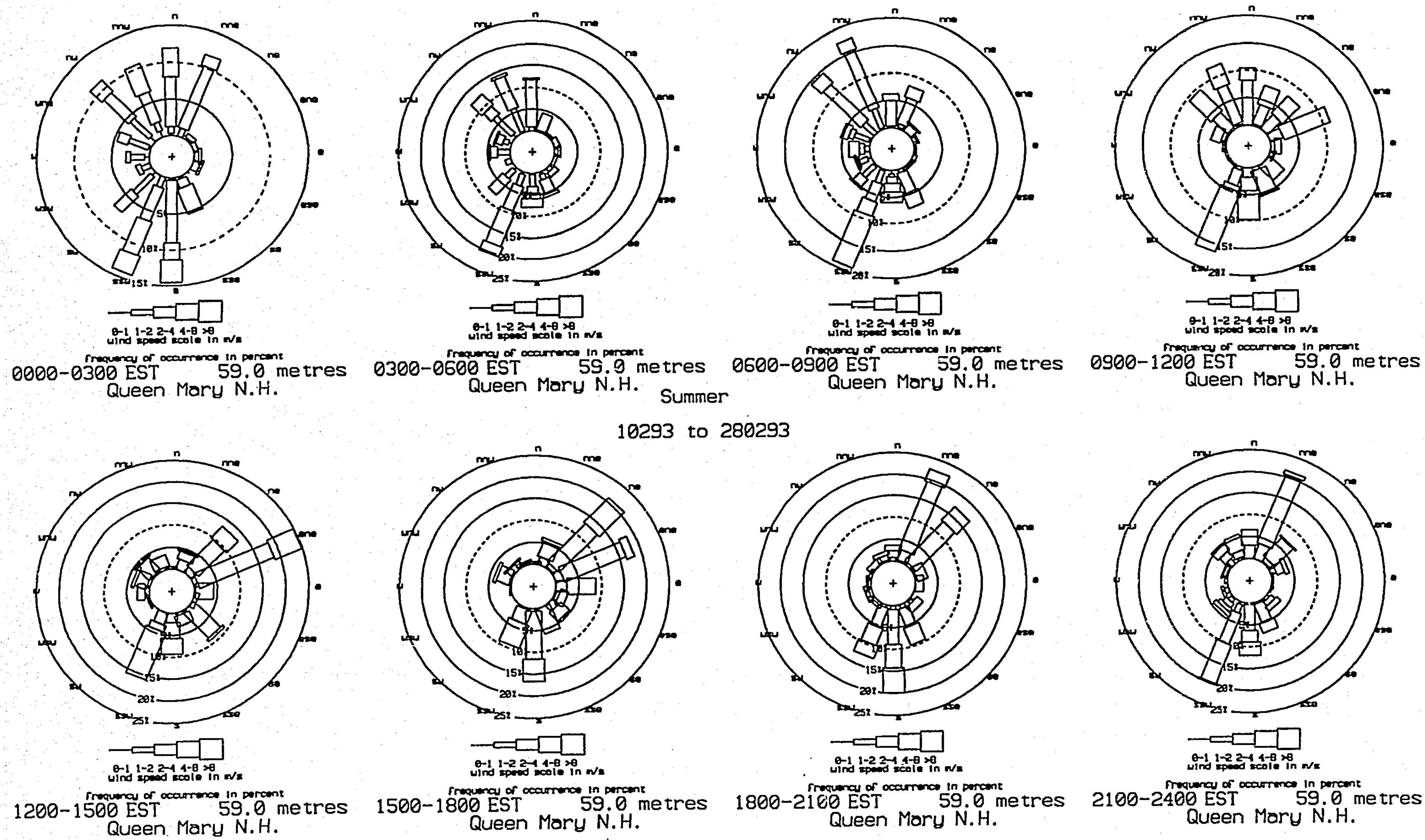


Figure 3 - Summer Bailley-type wind roses - Queen Mary Nursing Home.

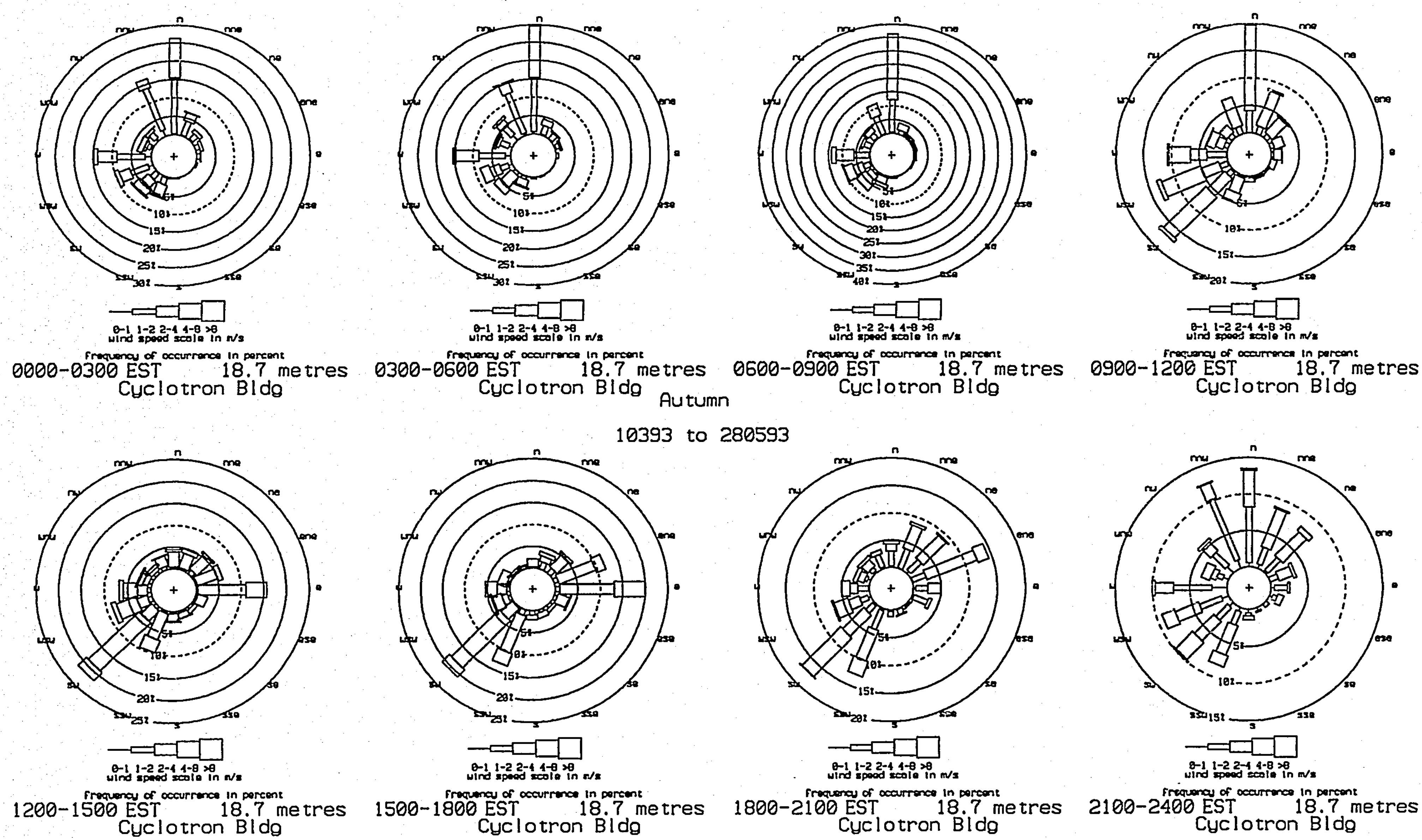


Figure 4 - Autumn Bailley-type wind roses - Cyclotron Building.

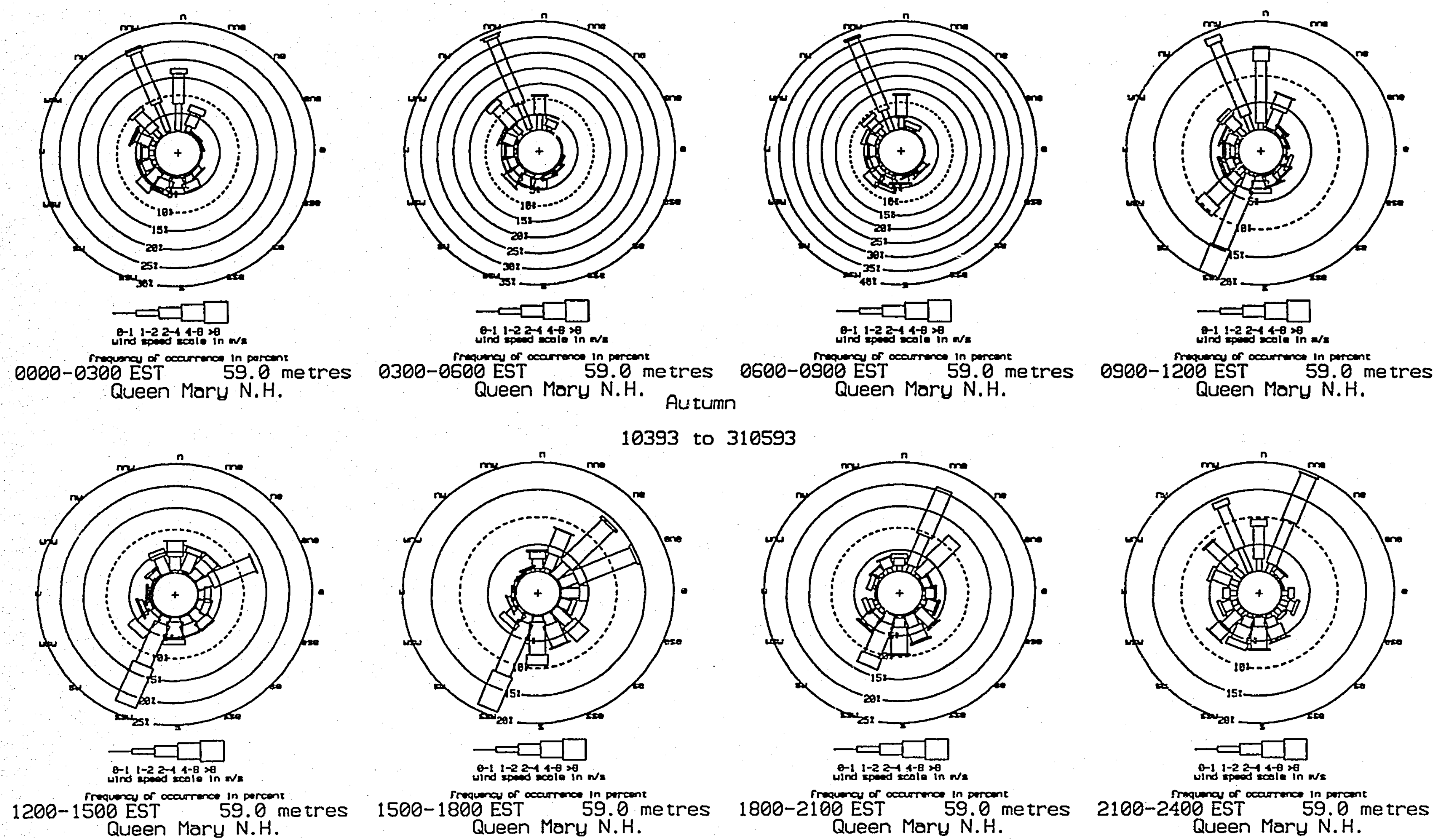


Figure 5 - Autumn Bailley-type wind roses - Queen Mary Nursing Home.

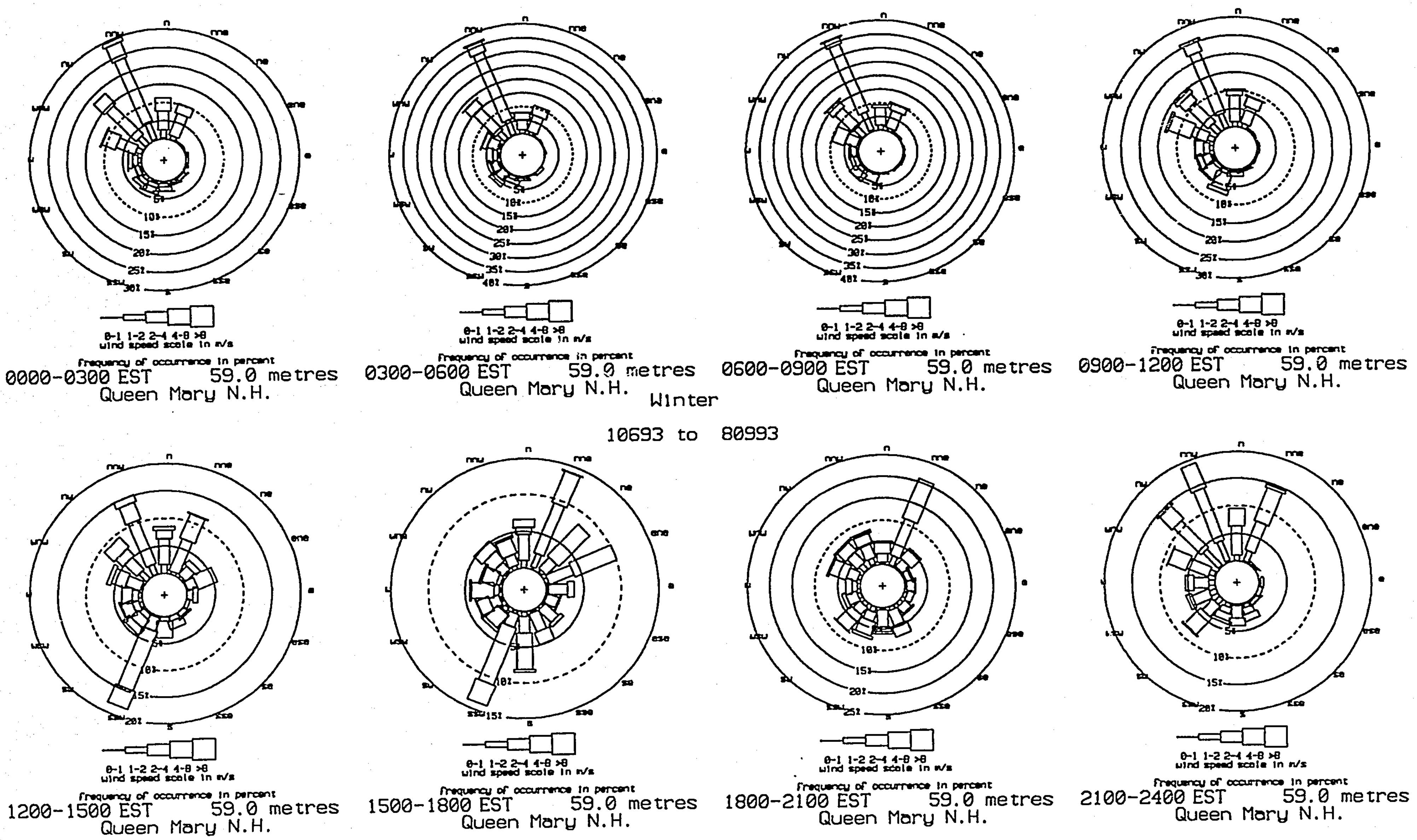


Figure 6 - Winter Bailley-type wind roses - Queen Mary Nursing Home.